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Wood compost process engineering, properties and its impact on extreme soil characteristics

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ZUSAMMENFASSUNG

Entsprechend der Zielstellung wurden zunächst verschiedene Varianten der Kompostierung von Holzsubstanz getestet, um eine optimale Technologie, die auch für Entwicklungsländer realisierbar ist, herauszufinden. Hierzu sind in Pflanztöpfe Holzspäne (Woodchips) von zwei verschieden Holzarten (Laub- und Nadelholz) gefüllt und mit verschiedenen natürlichen Stickstoffquellen gemischt worden. Diese Ansätze wurden regelmäßig mit Kompostwasser appliziert. Nach vier Wochen sind zwei verschiedene Wurmarten (*Dendrobaena veneta* und *Eisenia fetida*) hinzugegeben worden. Die Feuchthaltung erfolgte ab diesem Zeitpunkt durch Frischwasser.

Die qualitativ beste Versuchsvariante ist im nächsten Schritt mit weiteren natürlichen Stickstoffquellen, die in Entwicklungsländern zur Verfügung gestellt werden könnten, getestet worden. Von allen Kompostvarianten sind im Labor eine Vielzahl von bodenphysikalischen (z.B. Dichte, Wasserhaltekapazität) und bodenchemischen Zustandsgrößen (z.B. Elektrische Leitfähigkeit, Totalgehalte biophiler Elemente, Bodenreaktion, organische Substanzgehalte, Kationenaustauschkapazität) bestimmt worden.

Die Wiederum qualitativ beste Mischung ist in einer weiteren Versuchsreihe in verschiedenen Mengenverhältnissen mit tertiärerem Abraumsand des Braunkohlebergbaus gemischt worden. In diese Versuchsmischungen wurde die Grasmischung *RSM* 7.2.1 eingesät und regelmäßig bewässert sowie die Wuchshöhe gemessen. Nach 42 Tagen wurden das Gras geerntet und die biometrischen Parameter, die Nährstoffgehalte (pflanzenverfügbare Fraktionen), die Bodenreaktion, die effektive bzw. potentielle Kationenaustauschkapazität sowie die Pufferkapazitäten der Mischsubstrate bestimmt.

Die nächsten Versuchsvarianten sind als Feldversuche in der Niederlausitz durchgeführt worden. Für ihre Realisierung wurde als weiterer Zuschlagsstoff Arkadolith® zugemischt. Die Plotflächen sind sowohl auf Abraumsanden des Tertiärs als auch Quartärs angelegt worden. In jeweils eine Subvariante ist *RSM* 7.2.1, in die andere eine autochthone Grasmischung eingesät worden. Diese Experimente wurden nach 6 Monaten beendet, die Bestimmung aller Parameter erfolgte in gleicher Weise wie bei den Gewächshausversuchen.
Auf Basis aller Versuchsreihen konnten die besten Kompostqualitäten und ihre optimalen Herstellungsvarianten ermittelt werden.

Eine weitere Aufgabe war es zu untersuchen, wie im Vergleich zur Verbrennung von Holzmasse die CO_2-Emission in die Atmosphäre durch Holzkompostierung verringert werden kann. Hierzu wurde während der verschiedenen Kompostierungsvarianten die CO_2-Freisetzung gemessen. Im Vergleich dazu ist jeweils die gleiche Masse an Holzsubstanz verbrannt worden. Die Ergebnisse zeigten, dass im Vergleich zu der thermischen Verwertung von Holsubstanz die CO_2-Emission bis zu 50 % verringert werden kann. Dem Boden kann darüber hinaus energiereiche organische Substanz zugeführt werden, die eine Entwicklung der Bodenorganismen ermöglicht.

Ein weiteres Experiment zielte darauf ab, die Stabilität der Holzkomposte zu bestimmen. Darüber hinaus sollte untersucht werden, ob durch die Zufuhr von pyrogenem Kohlenstoff eine Vergrößerung der Stabilität zu erreichen ist. Diese Untersuchungen wurden mit Hilfe der Thermogravimetrie vorgenommen. Alle wichtigen Kompostierungsvarianten sind sowohl mit verschiedenen Zusatzmengen als auch ohne Zusatz von pyrogenem Kohlenstoff vermessen worden. Als Vergleichssubstanz diente der Oberboden eines Niedermoorgleys, der naturgemäß einen relativ hohen Anteil an organischer Substanz aufweist.

Die Ergebnisse zeigten, dass im Bereich niedriger Temperaturen die Wasserbindung im Naturboden fester ist. In der Fraktion der oxidierbaren organischen Substanz, im mittleren

Temperaturbereich gemessen, ist die natürliche Bodensubstanz ebenfalls stabiler, was auf eine intensivere Bindung zwischen den organischen und anorganischen Bestandteilen, also auf stabilere organisch-mineralische Komplexe, schlussfolgern lässt. Im Bereich höherer Temperaturen (T> 550° C) waren im Naturboden keine nennenswerten organischen Bestandteile mehr nachweisbar. Hingegen wiesen die Kompostvarianten einen hohen Anteil stabiler Fraktionen, vor allem aromatische Verbindungen, auf. Diese Aussagen erscheinen vor allem für die praktische Anwendung der Holzkomposte in Hinblick auf ihre Langzeitwirkung bedeutsam. Der Zusatz von pyrogenem Kohlenstoff zeigte keine zusätzliche Stabilisierungswirkung.

ABSTRACT

The landfilling of biodegradable waste is proven to contribute to environmental degradation. Much wood and lumber is discharged as waste from the cleared fields. These woody wastes are subsequently disposed of by burning. However, it would be preferable to dispose of them without combustion to avoid the release of carbon dioxide, one of the critical greenhouse gases. Instead of burning these woody wastes, we should recycle them as future resources. One solution to this problem is to make compost from the waste. Compost use in agriculture is increasing as both an alternative to landfilling for the management of biodegradable waste, as well as means of increasing or preserving soil organic matter. This research aimed to contribute to the identification of a system for managing the production and utilization of wood waste (*Quercus rubra and Pinus sylvestris*) compost for sustainable agriculture, with particular regards to carbon dioxide produced from both compost and combustion of wood.

Compost of wood was implemented in two consecutive trials. The first was carried out in greenhouse experiment in 4 liter pot of *Quercus rubra and Pinus sylvestris (QR and PS)* moisted by compost and tap water and infected by tiger worm (*Eisenia fetida, EF*) and European night crawlers (*Dendrobaena veneta, DV*) at different mixed ratios with lake mud (LM). The second was conducted in greenhouse experiment in 40 liter pot of the successful wood and worm from the first compost trial (*QR* and *EF* respectively). The tested wood (*QR*) was mixed separately by lake mud and horse manure and irrigated by compost and tap water.

The final product, successful wood compost (*QR*) produced from the first trial (4 liter pot) was utilized in different mixed ratios with coal mine tailings (tertiary sand) in greenhouse pot trial to study his effects on improving soil physical and chemical properties and some plant growth parameters of *RSM* 7.2.1 grass. The wood compost produced from the second compost experiment (40 liter pot) and other artificial component named Arkadolith® were used as soil amelioration in field experiments of different selected sites with extremely unsuitable characteristics (tertiary and quaternary sand in Lusatia lignite region, Germany). The soil in each site was sowed by *RSM* 7.2.1 and autochthonous grasses.

Also, some vermicompost samples were selected to study its thermal stability which compared with a soil sample (Niedermoorgleys) by using thermogravimetric analysis technique. Further investigation was achieved to evaluate the effect of charcoal as a source of carbon on vermicompost stability. Moreover some selected vermicompost samples were used to examine its microstructure under scanning electron microscope which compared also with the same soil used in thermal analysis.

The obtained results under all studied experiments can be arranged as follow:

First compost trial,

Cumulative amount of carbon dioxide produced during composting period was lower than that evolved by combustion of wood. The results showed composting of wood can reduce the emitted CO_2 up to 50 % when compared with the amount of CO_2 produced from combustion of wood. The effect of different studied factors on different studied parameters show that, *QR* wood compost have more responsive to decomposition processes and humification rate in comparison with PS wood compost. Under different infection worms, *Eisenia fetida* (*EF*) was better than *Dendrobaena veneta* (*DV*) in biodegradation rate. Compost water has had a better impact of tap water in all studied decomposition parameters. For example, The compost content of OM and total OC was decreased with the increase of the decomposition period in the treatments of compost water and *EF* worm, where this decrease was higher at mixed ratio of 1:3 (wood: mud, w/w). The total content of N in the final products takes reversible trend regarding to OM and C content. The high content of N was found in *QR* wood compost moisted by compost water and infected by *EF* worm. The content of both macro-and micro-nutrients was clearly positive affected by the studied factors. The content of these nutrients in *QR* wood compost was higher than that found in the compost of *PS* wood.

Second compost trial,

The observed data show that, the amount of CO_2 produced by composting was lower than that evolved by combustion of wood. Composting of wood reduced CO_2 emission up to 40 % of the combustion wood CO_2. Cumulative amount of CO_2 produced from wood compost treated by horse manure was higher than that fount in the other treated by LM. The compost of wood treated by horse manure has had a high decomposition rate in comparison with that treated by lake mud. The treatments left without worms during all composting period and moisted by compost water have a responsive effects but it was lower than that infected by worms. Total and available contents of N, P, K, Mg, Zn, and Cu in the compost treated by HM were higher than that found in compost treated by LM. The other nutrients (Ca, Fe, Cu, and Mn) take reversible trend, which it was higher in LM than HM treatments.

Thermal and microstructure analysis,

The selected vermicompost samples from both first and second compost experiments showed, up to 200° C temperature the mass loss was due to free water and bound water (It was in vermicompost samples higher than soil sample). Mass loss from 200 to 550° C is due to easily oxidizable organic forms and it was higher in vermicompost than soil. In this stage the soil OM seems to be more stable than vermicompost which can be explained by a more intensive bond between the organic and inorganic components. At higher temperatures (T> 550° C) no significant detectable was appeared of soil organic matter. In contrast, the vermicompost treatments showed a high proportion of stable groups, especially aromatic compounds. These statements seem to be importance particularly for the practical application of the wood compost in terms of their long-term effect in the soil. The application of charcoal, showed no additional stabilizing effect of vermicompost. Also, the data show that, vermicompost structure characterized with high homogeneity and ratio of surface area to volume compared to those in soil structure.

First plant trials (greenhouse),

Different compost mixed ratios had positive impact on different extreme soil physiochemical properties. At the end of experiment (42 days) compost increased soil water holding capacity, decreased soil bulk and particle density and increased total porosity. The used wood compost modified soil buffering capacity and soil acidity. The availability of soil macro and micro nutrients were increased after adding wood compost. The wood compost had a positive effect in some growth parameters like fresh and dry matter yield of the selected grass. High dry matter yield and nutrients uptake was achieved with higher rates of compost application (25.0% > 12.5% > 3.0% > 0.0 %, w/w).

Second plant trials (field experiment),

Regarding to the effect of wood compost (*QR*) and Arkadolith® component on tertiary and quaternary sand, at the end of grown season (6 month) most soil and plant characteristics of tertiary sand were improved and it was better than that in quaternary sand. This trend reveals to, physical and chemical properties of tertiary sand was better than that in quaternary sand, like organic matter content, CEC, WHC, TOC, available nutrients. In the both sites, the effects of different type of soil conditioners arranged as follow: the treatments treated with wood compost is the better followed by the other treated with both wood compost and Arkadolith. Wood compost increased soil pH, CEC, soil buffering capacity, OM content, and soil WHC in comparison with Arkadolith which make a small improvement of these properties in both sites. Finally, Different growth parameters (height, covering, fresh and dry matter yield) of the used grasses were clearly positive affected by wood compost, with the highest production inherent to the treatments treated by the high amount of wood compost.

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LIST OF ABBREVIATIONS

A	Autoch grass (Autochthonous)
AE	Agronomic efficiency
AIF	Arbeitsgemeinschaft Industrielle Forschung
ANOVA	Analysis of variance
APHA	American Public Health Association
ARK	Arkadolith
BD	Bulk density
BS	Base saturation
C:N	Carbon to nitrogen ratio
CEC	Cation exchange capacity
C_{FA}	Carbon of fulvic acid
C_{HA}	Carbon of humic acid
DB	Degree of biodegradation
DH	Degree of humification
DIN	Deutsches Institut für Normung (in English, the German Institute for Standardization)
DM	Dry matter
DMY	Dry matter yield
DTA	Different thermal analysis
DTG	Differential thermogravimetric
DV	*Dendrobaena veneta*
EA	Environment Agency
EC	Electrical conductivity
ECEC	Effective Cation exchange capacity
EDTA	Ethylene diamine tetra acetic acid
EF	*Eisenia fetida*
EPA	Environmental Protection Agency
FA	Fulvic acid
FMY	Fresh matter yield
HA	Humic acid
HI	Humification index
HM	Hors manure
HR	Humification rate
IPCC	Intergovernmental panel on climate change
ISO	International Organization for Standardization
LM	Lake mud
LSD	Least significant difference
NPK	Nitrogen, Phosphorus, Potassium
NRAES	Natural Resource, Agriculture, and Engineering Service
OM	Organic matter

Org.C	Organic carbon
PCEC	Potential cation exchange capacity
PD	Particle density
PS	*Pinus sylvestris*
Q	Quaternary
QR	*Quercus rubra*
R	*RSM* 7.2.1 grass
RE	Relative increasing
ROU	Recycle organic unit
SEM	Scanning electron microscopy
T	Tertiary
TC	Total carbon
TEA	Total exchangeable acidity
TEB	Total exchangeable bases
TEC	Total extractable carbon
TG	Thermogravimetric
TN	Total nitrogen
TOC	Total organic carbon
TP	Total porosity
TS	Total sulphur
US	United states
USDA	United states department of agriculture
WC	Wood chips
WHC	Water holding capacity
WRAP	Waste resources and action programme

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1. INTRODUCTION

1.1. General

Currently, large tracts of forest are clear-cut to make way for construction projects such as hydroelectric power stations, substations, golf courses, land use change by economic agricultures and so on. Much wood and lumber is discharged as waste from the cleared fields. These woody wastes are subsequently disposed of by burning in the field. On the other hand, there are many power station in several countries used these woods to produce energy. Wood combustion for electricity and heat is one way in which forest products companies can utilize their wood residues. Typically, wood in a variety of forms, particularly green chips (45% to 50% moisture content on a wet basis), is shipped and maintained at a holding site by the energy plant. Augers or belt conveyors transport the wood chips to the combustor, where they are burned, and the heat of combustion is transferred to a steam or hot water boiler. Steam is converted to electrical power by steam turbines. Hot water boilers can provide heat to a building through a piping distribution network.

However, it would be preferable to dispose of wood without combustion to avoid the release of carbon dioxide (CO_2), one of the critical greenhouse gases. Instead of burning these woody wastes, we should recycle them as future resources. One solution to this problem is to make compost from the waste. However, woodchips are difficult to decompose because of the complex chemical structure of lignocelluloses. Previous efforts have developed methods of producing wood composts from such sources as bark (KAWADA, 1979) or saw dust and wood shavings (ZOES et al., 2001), as well as methods of estimating their maturity. Moreover, there have been few reports on firmly established methods of determining the mixing ratio of the initial ingredients and estimating index maturity of the final woodchips composts (TAKESHI et al., 2004).

Composting is useful in avoiding green house gas emissions, as it is an aerobic process. MOHAREB et al. (2004) reported that, composting with sufficient aeration generates biogenic CO_2 instead of CH_4 from the degradation of organic materials. It also reduces emissions from organic waste by a significant amount, compared to landfilling without energy recovery (1.2 t CO_2 equivalent/t for food wastes and 0.7 t CO_2 equivalent/t for yard trimmings). Moreover, there are many studies showed the big amounts of CO_2 producing by combustion of wood. These studies suggested the main compound emitted is CO_2, which presents between 85% and 90% of the carbon released into the atmosphere (LOBERT et al., 1991; LOBERT & WARNATZ, 1993).

Furthermore, composting and vermicomposting products are of great interest in modern agriculture where agronomic practices cause substantial loss of soil organic matter; this loss should be rapidly replaced in order to restore the soil fertility functions relating to the quality and quantity of organic matter. The use of immature compost is well known to cause more adverse than beneficial effects on the soil environment and agricultural production. In addition, compost nutrients are released slowly, allowing them to stay in the soil for a period of up to five years. So, while chemical fertilizers may contain more available nitrogen, phosphorous, and potassium than compost, compost allows these and other nutrients to be consumed by plant roots as they are needed. Slow release of nutrients in compost means there is also no danger of over-fertilizing plants. Compost increases soil workability, water holding capacity, porosity and drainage, compost minimizes wind and water erosion. Soil temperatures are moderated, making plants less susceptible to extremes of heat or cold. Furthermore, compost creates enhances microbial action in the soil. This creates a stable ecosystem for beneficial insects, birds, and other organisms, which keeps pests in check and trigger plants' natural defenses against disease. Healthier plants lessen the need for fertilizers or pesticides. Less fertilizers and pesticides pose less of a danger to animals and humans who are exposed to toxic residuals through food, water, soil and air.

Composting is a process in which organic wastes of different origins and natures are transformed into relatively stable humic materials. This process involves various microorganisms and worms. The main products of the process are CO_2, water, and NH_4, a composite pool of microorganisms, minerals and stabilized organic matter, consisting mainly of humic-like materials. The composting process does not differ greatly from the natural transformation phenomena to which organic matter is subjected in soil, and consequently it is expected to have only a limited impact on the soil environment (PROVENZANO et al., 2000).

In addition, using worms in the degradation and decomposition of biowaste to more useful product is featured prominently last time. This process is called vermicomposting which involving interactions between earthworms and microorganisms. Although the microorganisms are responsible for the biochemical degradation of the organic matter, earthworms are the crucial drivers of the process by fragmenting and conditioning the substrate, increasing surface area for microbiological activity, and altering its biological activity dramatically (EDWARDS, 2004).

Furthermore, an integrated system from both the thermophilic composting process and the vermicomposting process would be necessary to provide a product free of pathogens, and product with desirable characteristics at a faster rate than either of the individual processes.

1.2. Statement of problems

To obtain high quality compost, it is necessary to understand the mechanism of the composting process. Although the principles of composting for different kinds of waste are mostly the same, the individual properties of particular waste materials can have their special characters during composting. Wood contains high concentrations of difficult degradable organic substances such as lignin, cellulose and hemicelluloses, and low amount of easily degradable organic substances like sugars, starches, lipids and proteins. Moreover, being wood is low in moisture content and dense in weight. Although composting is not a new wood disposal method, the characteristics of wood still offer a unique challenge, since the basic knowledge of composting is inadequate for supporting a successful processing of the wood composting (TAKESHI et al., 2004). Therefore, composting for wood in different systems has not gained increased attention in the past decade. Although considerable amount of the existing literature concerns the optimization of wood composting operations to achieve a high decomposition rate and a stabilized end product, less information is available concerning the fate of carbon dioxide producing during wood composting and the CO_2 evolved by burning of wood.

One of the problems which this study focuses on is the CO_2 emitted by combustion of wood. A large quantity of wood resulted from lumber and clear-cut of forest, this woody waste occupies large areas. Some people use this wood to make furniture or used in many different industries and the other like in Africa are burning wood to dispose of them. Moreover, currently the main exploited for this wood was in power station to obtain the energy. The amount of CO_2 evolved by burning wood was around 1400-1700 g per kg wood (ANDREAE, 1991); this amount can cause a series of environmental problems such as raise earth warming and pollution. It would be preferable to dispose of them without combustion to avoid the release of carbon dioxide, one of the critical greenhouse gases.

On the other hand, to examine the final product produced from composting of wood, it should be preferable using it in soil with extreme characteristics. To find out if this compost has a positive or negative impact on this soil. Therefore the other problem studied was the extreme soil characteristics in Lusatian lignite region (Eastern Germany). This soil (open-cast lignite) covered by spoil heaps of clastic overburden sediments of tertiary and quaternary age (HUETTL & WEBER, 2001). A serious problems that has to be considered when recultivation these substrata. The pyrite content in these substrates when exposed to the atmosphere leads to a high potential for acid production and consequently very phytotoxic site conditions. Sulphuric acid is formed and mobilized in these raw soils during the chemical weathering of the sulphide minerals (marcasite and pyrite). This causes an extreme acid soil reaction which impedes the success of mine soil reclamation and revegetation practices. Other negative properties are reduced wettability of the soil, low nutrient contents and pedogenic organic matter, insufficient soil life and disturbed air-water balances. Erosion and transportation accelerates weathering. Reduced infiltration will hinder plant growth as soil water is not renewed (WANG et al., 2000).

1.3. Statement of the hypothesis and research objectives

It is hypothesized that:

1. Compost and vermicompost of wood is an alternative approach to dispose of woody wastes and may be a sustainable procedure to carbon dioxide emission reducing.
2. The final product of wood composting is one of the soil conditioners which can be used to improve and ameliorate different extreme soils of coal mine tailings in tertiary and quaternary sand and it will result in improved soil chemical, physical and planting properties.

To test the previous hypothesizes, the following research objectives were established as shown in Figure 1.1.

First objective: Examine the factors affecting the design and implementation of a wood composting scheme. For studying this objective the following experiments will be investigated:

First compost experiment: Test the ability of two species of wood to produce compost in greenhouse experiment.

In detail, the following aspects will be investigated: a) Comparison between the amounts of CO_2 produced during composting period and the other evolved by combustion of wood. b) Evaluate the compost stability and maturity by measuring (temperature, organic matter, total organic carbon, total extractable carbon, humic substances and humification parameters) during composting period. c) Estimate the compost chemical and physical properties. d) Evaluate macro and micro nutrient content of the final product. e) Evaluate the compost microstructure under microscope. f) Assess the organic matter stability of the selected treatments using different thermal analysis (DTA) and thermogravimetric (TG) method.

Second compost experiment: Using the successful wood and worm types from the first experiment in more big compost pots experiment. As showed previously, the same parameters will be examined.

Second objective: Examine the quality of composted wood produced from the first and second compost experiments by utilizing it to improve extreme soil characteristics in different selected sites of coal mine tailings. For studying this objective the following experiments will be investigated:

First plant experiment: Evaluate the effect of the successful wood compost produced from the first compost trial in improvement soil physical, chemical and plant properties of tertiary sand in greenhouse trial.

In detail, the following aspects will be investigated: a) Soil physical properties (microstructure, bulk density, particle density, total porosity and water holding capacity). b) Soil chemical properties (pH, electrical conductivity, cation exchange capacity, organic matter content, total carbon, total nitrogen, buffering capacity, available macro and micro nutrients content). c) Plant growth parameters (plant height, covering, fresh and dry matter yield).

Second plant experiment: Evaluate the effect of the wood compost produced from the second compost trial in improvement soil physical, chemical and plant properties in field experiments.

In details, the wood compost and another soil conditioner (Arkadolith, ARK) will use to test its impact on tertiary and quaternary sand in different selected sites. The soil in each site was sowed with two types of grass, *RSM* 7.2.1 and autochthonous (Autoch). The following aspects will be investigated: a) Soil physical properties (bulk density, water holding capacity). b) Soil chemical properties (pH, electrical conductivity, cation exchange capacity, organic matter content, total carbon, and total nitrogen). c) Plant growth parameters (plant height, covering, fresh and dry matter yield).

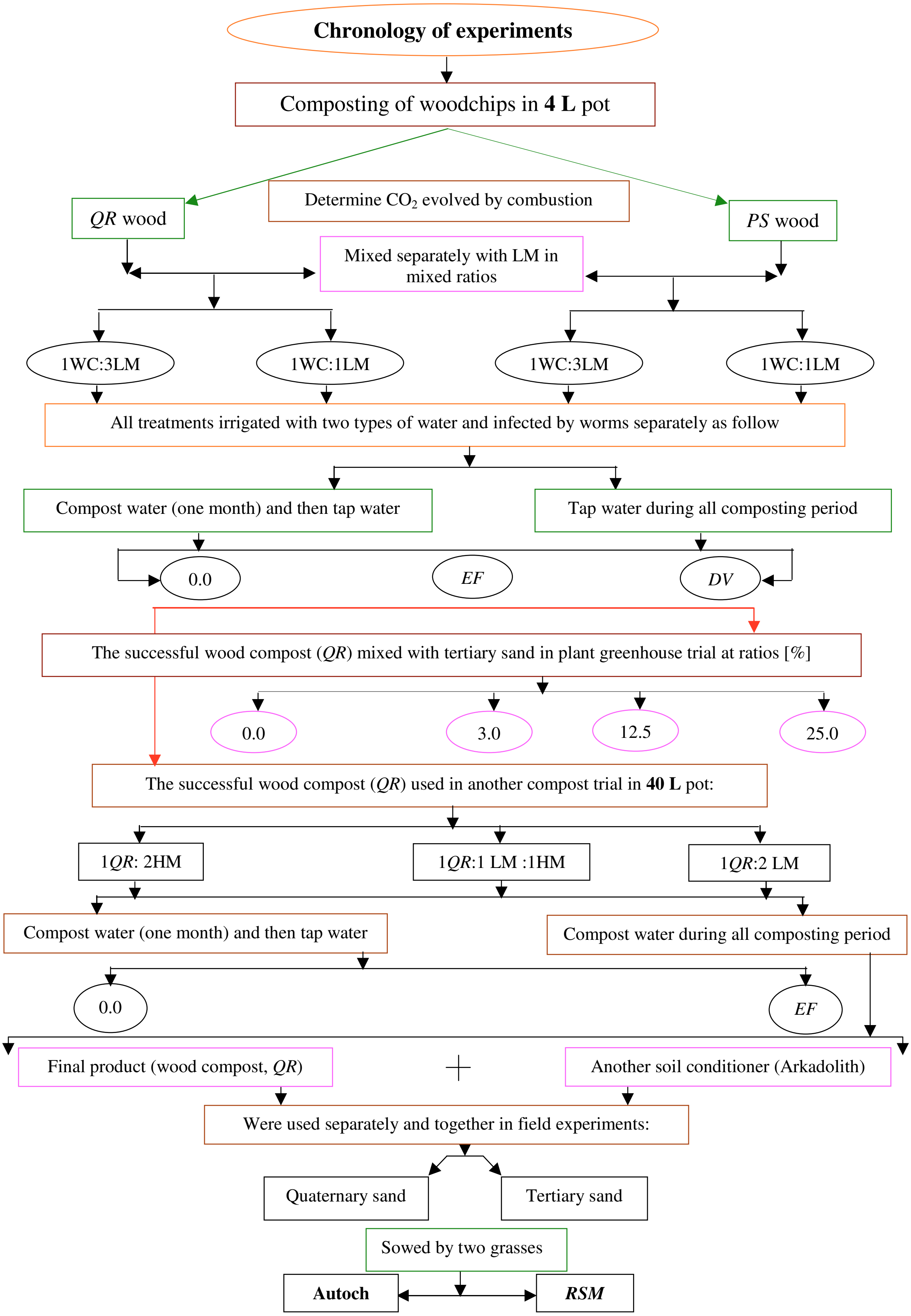

Fig. 1.1: Experiments approach

QR = *Quercus rubra*
EF = *Eisenia fetida*
PS = *Pinus sylvestris*,
DV = *Dendrobaena veneta*
LM=Lake mud
WC = Wood chips
HM = Horse manure

2. REVIEW OF LITERATURE

2.1. Introduction

A number of solid waste disposal strategies have been adopted around the world. The major disposal technologies include, open dumping, hog feeding, land filling, land spreading, composting, lime stabilization, thermal drying (including pelletization) and incineration. Each solution has benefits and limitations. No single solution has universal applicability. In such a scenario, there is an obvious need to reuse and recycle the solid wastes. In the past years, several new methods, mainly based on biological processes have been developed to convert solid wastes into energy and organic fertilizers. All these conversion processes create useful products that can be marketed. Waste management under these conditions gets a completely different image and perspective, compared to the actual state of the art. These methods include a) Composting, b) Vermicomposting, c) Biomethanation and, d) Ferti-irrigation (VINOD et al., 2008).

Vermicomposting is the conversion of biodegradable garbage into a high quality chemical free bio-fertilizer with the aid of earthworms. Whereas, the composting is take the other way round where the organic part of the refuse is consumed by a series of successive bacteria according to the heat of the system. Earthworms have from time immemorial played a key role in soil biology by serving as versatile natural bioreactors to harness and destroy soil pathogens, thus converting organic wastes into valuable bio-fertilizers, enzymes, growth hormones and proteinaceous worm biomass. The worms do it by feeding voraciously on all biodegradable refuse such as leaves, paper (non-aromatic), kitchen waste, vegetable refuse. Certain types of earthworms ingest, digest, and excrete vermicompost with excellent nutrient content (ARACON et al., 2007). Ingestion ensures the sorting out of only organic matter while the digestion accelerates the maturing process. Excretion ensures the grading of the vermicompost as opposed to any inorganic matter, which may be existing in the waste and not concerned with the biological activity in the earthworm gut. On the other side, during the composting process, microorganisms decompose organic compounds, which consist of carbohydrates, sugar, proteins, fats, cellulose and lignin (TENZIN, 2002).

2.2. Principal of composting

2.2.1. Definition

Composting is the bioconversion, decomposition of organic biodegradable materials by heterotrophic microorganisms (bacteria, fungi, actinomycetes and protozoa) into humus-like material called compost (EPSTEIN, 1997). It has become one of the most important waste technologies. The process occurs naturally provided the fight organisms, moisture, aerobic conditions, feed material and nutrients are available for microbial growth. By controlling these factors the composting process can occur at a much faster rate (VINOD et al., 2008).

2.2.2. Composting process

The composting process can be divided into two main periods: (1) active composting and (2) curing. Active composting is the period of vigorous microbial activity during which readily degradable material is decomposed as well as some of the more decay-resistant material, such as cellulose. Curing follows active composting and is characterized by a lower level of microbial activity and the further decomposition of the products of the active composting stage. When curing has reached its final stage, the compost is said to be stabilized. The final product containing stabilized carbon, nitrogen and other nutrients in the organic fraction, the stability depending on the compost maturity (ZWART, 2003). The stable by-products of this decomposition, the biomass of both dead and living microorganisms, and the under gradable parts of the raw material make up the end product that is called ***compost***.

The process is managed to achieve the favorable conditions required for microorganisms to proliferate, accelerate the biodegradable process, reduce the emission of unwanted gases (NGNIKAM et al., 2002) and, at the same time destroy pathogenic bacteria (VINNERAS et al., 2003). The input and output of the composting process are illustrated in Fig 2.1. The composting rate is dependent on the type of organic matter used as a substratum. Simple organic matter such as sugar and carbohydrates decompose more rapidly compared with leaves and woodchips which are more complex lignocellulosic materials of low biodegrability (EPSTEIN, 1997). Sawdust and shavings, like other wood wastes, are low in N and P and therefore are composted best in combination with other counter-balancing materials, or with N and P fertilizers. Wood wastes contain hemicelluloses and celluloses that degrade easily, and the recalcitrant lignins that contribute heavily to humus formation. During decomposition phenolic compounds and polymers release bioinhibitory phenols, terpenes and tannins periodically so that the process of wood waste composting is staggered rather than continuous (MATHUR, 1991).

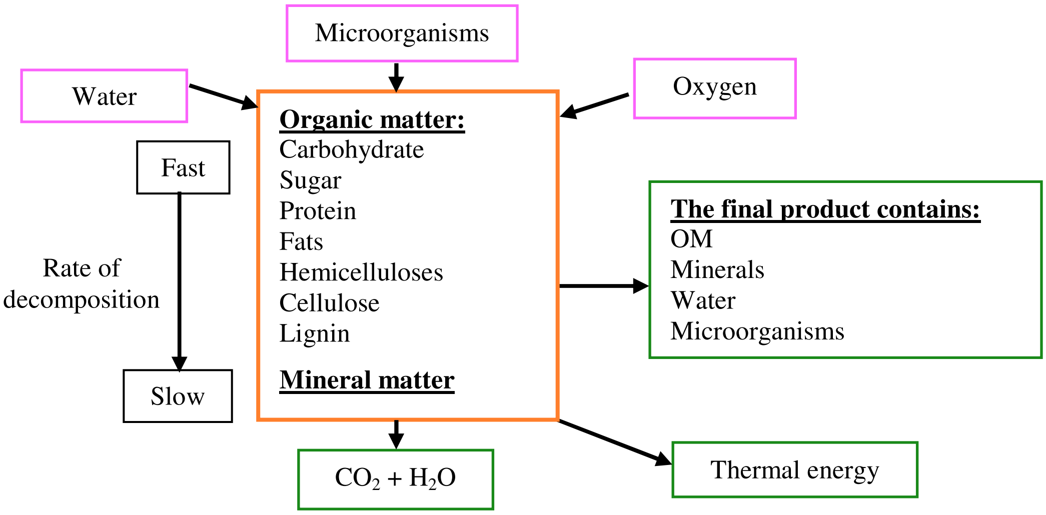

Fig. 2.1: Schematic diagram of composting process (after EPSTEIN, 1997; NRAES, 1999)

2.2.3. Factors affecting on composting process

2.2.3.1. Oxygen and aeration

The most common microorganisms in the biodegradation of waste are bacteria and fungi. During degradation, oxygen is consumed and CO_2 and water released (TENZIN, 2002). When oxygen is lacking, the anaerobic conditions prevail. The anaerobic process produces odorous gases such as ammonia and hydrogen sulfide (FUKUMOTO et al., 2003). DRUILHE et al., (2002) demonstrated that, Continued metabolism depends on sufficient aeration. Average O_2 concentration inside the compost mix is 15 to 20 %, while CO_2 is 0.5 to 5 %. When O_2 content falls below these levels, anaerobic microbial populations surpass aerobic species. As a result, malodorous fatty acids and methane levels may increase. It is therefore important to ensure that aerobic processes are maintained through the composting period (BECK-FRIIS et al., 2003).

2.2.3.2. Temperature

Temperature is one of the most important process factors in composting because it determines the species mix of microorganisms in the compost system. Temperatures between 28 and 55° C are optimal. Few species of bacteria can survive at temperatures above 70° C. Fungi capable of degrading cellulose and lignin are also greatly inhibited by high temperatures (NATHAN, 2004). Substrates must reach 55° C for three consecutive days or more, or temperature of the coolest part of the compost must remain at 55° C for at least three consecutive days (NDEGWA & THOMPSON, 2001). The author mentioned that 55° C for 3 days was enough for pathogen content to be reduced to acceptable levels. Temperature within a composting mass is important for 2 reasons (MICHAEL

& KATHLEEN, 2001): i) to maximize decomposition rates; and ii) to produce a material that is microbiologically safe for use. Temperatures above 60-65° C reduced the rate of bio-oxidation in bench scale studies. Temperatures above 70° C reduce activity and even produce a false indication of process completion.

2.2.3.3. Particle size, porosity, structure and texture

The physical properties of the raw materials affect the composting process by their influence on aeration. They can be adjusted by the selection and mixing of raw materials. Any materials added to adjust these properties are known as bulking agents. Particle size reduction is one of the first steps of the composting process in most of the facilities (CHIUMENTI et al., 2005). Texture is the characteristic that describes the available surface area for aerobic micro-organism activity. The majority of aerobic decomposition occurs on the surface of particles because oxygen moves readily as a gas through pore spaces, but much slower through liquid and solid portions of the particles. For most raw materials and composting applications, an acceptable porosity and structure can be achieved if the moisture content is less than 65 %. Since the amount of surface area increases with smaller particle size, the rate of aerobic decomposition also increases with smaller particle size to a certain extent. Smaller particles reduce the effective porosity and therefore a compromise is needed. An average of between 10mm to 50mm in diameter will generally produce the best results. However certain composting methods that do not include a turning process require more a more robust physical structure to resist settling, so larger particles is necessary (greater than 50mm) (BECK-FRIIS et al., 2003).

2.2.3.4. Compost reaction (pH)

There are certain types of microorganisms that are dependent on pH for growth (EPSTEIN et al., 1997). The bacteria that require pH of 5 or less for maximal growth called acidophilic and the bacteria which growth best between pH 7 to 12 are termed as alkalophilic. Bacteria that prefer to grow at pH near 7 are known as neutrophilic. EPSTEIN (1997) also suggested that the range of pH that produces high temperature for longest period of time is from pH 6.5 to 9.6. SMARS et al. (2002) has suggested that actively preventing the temperature from rising until pH reaches a certain value could reduce the degradation time. This is further evidence that pH is one of the controlling factors in the composting process. Environment Agency (2001) reported that, the composting process can work over a wide spectrum of pH values, but a range of between 6.5 and 8.0 is preferred. Although the composting process will be less effective at the extreme ranges of 5.5 and 9.0 it will still work. A pH above 8.5 encourages the conversion of nitrogen compounds to ammonia, which further adds to the alkalinity.

2.2.3.5. Carbon to nitrogen ratio

The amounts of carbon or nitrogen are the substances most likely to affect the composting process by their presence in insufficient or excessive quantities. Nitrogen is used by micro-organisms for protein manufacture and for reproduction and carbon is used for energy and growth. Generally speaking, biological organisms need about 25 times more carbon than nitrogen. Raw materials mixed to provide a C:N ratio of 25:1 to 30:1 are generally accepted as ideal for active composting, although ratios from 20:1 up to 40:1 can give good composting results (GOLUEKE, 1994; ROU, 2000c; LAST, 2006; MARIA, 2008). Low C:N ratios of below 20:1 allow the carbon to be fully utilized without stabilizing the nitrogen, which may be lost as ammonia or nitrous oxide. This can cause odour problems. Ratios of composting materials with carbon content higher than 40:1 require longer composting periods while the excess carbon is used by the micro-organisms (EA, 2001). The rate at which carbon compounds decompose must also be considered. If the carbon is in a form that is difficult to decompose, the composting rate may be slower (e.g. wood wastes).

2.2.3.6. Moisture

Moisture supports the metabolic processes of the micro-organisms. Water is the medium for chemical reactions, transportation of nutrients and allows the microorganisms to move about. Biological activity ceases below 15 % moisture content and in theory activity is optimal when materials are saturated. Generally moisture content of between 40 % and 65 % should be maintained during composting period (RICHARD et al., 2002; ABU QDAIS & HAMODA, 2004). At moisture content of below 40 %, micro-organism activity will continue but at a slower rate and above 65 % water will displace much of the air in the pore spaces of the composting material. This will limit the movement of air and lead to anaerobic conditions. Moisture content should be above 40 % at the starting point, as it will generally decrease as composting proceeds. Therefore if the moisture content falls below 40 %, more water should be added to maintain optimum conditions (EA, 2001). Both wood and cardboard were often pre-wetted prior to adding to a composting mixture as suggested by WRAP (2005).

2.2.3.7. Microorganisms

Bacteria and fungi are the principle microorganisms in the composting system. Bacteria have a high surface area to volume ratio because of their small size. They are efficient at transferring oxygen and nutrients to produce a stable compost, water and carbon products. Bacteria dominate composting about 80 % to 90 % of the microorganisms in the compost. Most of the bacteria are not infections but there is always a possibility of pathogenic bacteria being present in the receiving waste. Fungi are multicultural microorganisms larger than typical bacteria. They are eukaryotic organisms that have a mucleus and other well-developed intracellular compartments. Many form long tubular, filamentous structures called hyphae. Fungi can tolerate lower moisture and require lower nitrogen level than bacteria (RYCKEBOER et al., 2003).

2.3. Composting of wood

Wood is one of the low biodegradability substances because of the presence of lignin that forms in the cell structure. Much research has been conducted to characterize these problems and a number of solutions suggested. One of them is by culturing specific bacteria to accelerate the degradability. Frequent turning of the compost stimulates xylan (a constituent of hemicelluloses) degradation by redistributing the substrata, the free enzymes and the microorganisms (PELTOLA et al., 2000). Wood is not as degradable as other compostable organic materials (RYNK et al., 1992) due to the presence of organic compounds such as lignin and lignocellulose that are relatively resistant to decomposition. This resistance to degradation may be somewhat enhanced in preservative and biocide treated composite wood products. In addition, the high carbon to nitrogen (C:N) ratio of woody materials impacts upon the efficiency of microbial processes. High C:N ratios slow the decomposition process, extending the composting time required. The blending of high C:N feedstocks with low C:N feedstock is one strategy used to increase decomposition rates. Woodchips are also used as bulking agents to adjust the physical properties of a composting mix. Adjustments are usually made to improve the porosity, structure, texture and particle size characteristics of compost. Moisture contents of windrows are in some instances adjusted with sawdust (RYNK et al., 1992; ROU, 2000c, 2007).

The presence of preservatives and biocides in the wood may further limit or slow down degradation. There are a number of basic parameters that a composter must control and optimize in order to compost wood waste effectively. These include oxygen, moisture, temperature and the C:N ratio of the feedstock mixture. This last parameter is controlled by mixing the wood waste (which has a typical C:N of between 300:1 and 700:1) with wastes of much lower C:N ratio, such as manures, biosolids (sewage sludge), grass clippings and food waste, in order to bring the C:N of the mixture to near 30:1 which is the optimum for a composting process (WRAP, 2007). A WRAP (2004) report on the use of treated wood waste looked at the options available for the composting of this type of material. Composting was put forward as the best practicable environmental option only for treated wood waste derived from packaging. Treated wood wastes from other sources, e.g. construction wastes and municipal solid waste were held to be unsuitable for composting because of the contamination of the composted products. Woody, lignin-rich waste components, e.g., tree and shrub clippings, bark, sawdust and shavings, and straw cannot be fed into the anaerobic process stages in large amounts (FRICKE et al., 2005). Composting materials are divided into two types, green and brown. Green materials include green leafy plant residues like weeds, grass clippings, vegetable tops and flower clippings. Brown materials include fall leaves, straw, sawdust, wood chips and shredded newspapers. To speed up decomposition, use two-parts green material to one-part brown material. Woody materials also require extra composting time and should be soaked in water before mixing with the compost raw materials (ROU, 2000a). Sawdust has been proven to be a good bulking agent for sludge composting; however, studies on the most suitable ratio of sludge: sawdust for sludge composting and on the influence of the sludge nature (aerobic or anaerobic) on the composting reaction rate is scarce (BANEGAS et al., 2007).

Large wood chips will take a very long time to break down and are often put to better use as mulch. WRAP (2005) reported that, wood waste should be shredded to <50 mm and mixed with shredded green waste and then co-composted with liquid wastes. So that there is a number of basic technology types used in the size reduction of residual wood and timber materials (composite or solid). These are used interchangeably to suit material quantity, size, shape and hardness. Machinery size largely depends upon the size of the feedstock materials a facility receives, and the amount of material to be processed (WILLIAMS & ENGEL, 1997). Price of machinery reflects capacity and maintenance requirements. Cheaper machines generally have lower processing capacities and higher maintenance requirements, as they may not have features that allow them to manage some contaminants (BIOCYCLE STAFF, 2000).

Wood composting methods

There a number of methods that may be utilized for the composting of wood and timber residuals. Some of these methods include (ROU, 2000b):

1) Turned windrow (aeration is achieved with a front-end loader or specialized equipment);
2) Passively aerated windrow (windrows constructed over perforated plastic pipes, which serve as air ducts for passive aeration);
3) Aerated static piles (aeration is achieved by a blower moving air through perforated plastic pipes located beneath a pile);
4) Aerated covered windrow (similar to an aerated static pile, with a cover over the feedstock);
5) Rotating drum (mixing and aeration occur with the rotation of a drum and forced aeration);
6) Agitated bed or channel (forced aeration and mechanical mixing are used in fully enclosed buildings); and
7) In-vessel systems (composting is achieved in an enclosed chamber subject to mechanical aeration).

2.4. Principle of vermicomposting process

2.4.1. Definition

Vermicomposting is a decomposition process involving interactions between earthworms and microorganisms. Although the microorganisms are responsible for the biochemical degradation of the organic matter, earthworms are the crucial drivers of the process by fragmenting and conditioning the substrate, increasing surface area for microbiological activity, and altering its biological activity dramatically (EDWARDS, 2004). Moreover, it is the process by which worms are used to convert organic materials into a humus-like material known as vermicompost (VINOD et al., 2008).

Vermicompost, which is the end product, is a stabilized, finely divided peat-like material with a low C:N ratio and high porosity and water-holding capacity that contains most nutrients in forms that are readily taken up by the plants (Fig 2.2). It also contains worms at various stages of development and other microorganisms associated with the composting processing (EDWARDS**,** 1995).

Fig. 2.2: Vermicompost

2.4.2. Factors affecting on vermicomposting process

Species of earthworms that can be used successfully in vermicomposting are relatively tolerant of the varied environmental conditions in organic wastes. However, it has been demonstrated clearly that these earthworm species have well-defined limits of tolerance to certain parameters, such as moisture and temperature, and that the wastes are processed much more efficiently under a relatively narrow range of favorable chemical and environmental conditions (EDWARDS, 2004).

2.4.2.1. Bedding and feeding

Bedding is any material that provides a relatively stable habitat to worms. For good vermicomposting, this habitat should satisfy the following criteria which suggested by VINOD et al. (2008):

- ***High absorbency***: As worms breathe through skin, the bedding must be able to absorb and retain adequate water.
- ***Good bulking potential***: The bulking potential of the material should be such that worms get oxygen properly.
- ***Low nitrogen content (high Carbon: Nitrogen ratio)***: Although worms consume their bedding as it breaks down, it is very important that this be a slow process. High protein/nitrogen levels can result in rapid degradation and associated heating may be fatal to worms.

On the other hand, when the material with high carbon content is used with C:N ratio exceeding 40:1, it is advisable to add nitrogen supplements to ensure effective decomposition. All organic matter should be added only as a limited layer as an excess of the former may generate heat (ISMAIL, 2005). Earthworms can consume practically all kinds of organic matter typically placed in a compost pile, such as food scraps, paper, plant residues, and they can eat their own body weight per day; thus, for example, one kilogram of worms can consume one kilogram of residues every day. The quantity and quality of food available in an ecosystem determines population size, composition and diversity of earthworm community (KAUSHIK & GARG, 2004).

2.4.2.2. Moisture content

Perhaps the most important requirement of earthworms is adequate moisture. In vermicomposting systems, the optimum range of moisture contents for most species has been reported to be between 50 and 90 % (DOMINGUEZ & EDWARDS, 1997). For example *Eisenia fetida* can survive in moisture ranges between 50 and 90% but grows more rapidly between 80 and 90 % in animal wastes, However, *Dendrobaena veneta* was able to withstand a much wider range of moisture contents than the other species (EDWARDS, 1988).The feed stock should not be too wet otherwise it may create anaerobic conditions which may be fatal to earthworms (VINOD et al., 2008). It is very important to moisten the dry bedding material before putting them in the bin, so that the over all moisture level is well balanced (SHERMAN, 2003).

2.4.2.3. Aeration

Worms suffer severe mortality partly because they are deprived of oxygen and partly because of toxic substances (e.g. ammonia) produced under such conditions. This is one of the main reasons for not including meat or other fatty/oily wastes in worm feedstock unless they have been pre-composted to break down the oils and fats (VINOD et al., 2008). Earthworms have no specialized respiratory organs; they obtain oxygen by diffusion through the body wall and lose carbon dioxide by diffusion. However, earthworms are very sensitive to anaerobic conditions, and their respiration rates are depressed in low oxygen concentrations of around 55 to 65 %, e.g., at oxygen levels of 0.25 its normal partial pressure (EDWARDS & BOHLEN, 1996); feeding activities might be reduced under these suboptimal conditions. Individuals of *E. fetida* and other species have been reported to migrate in large numbers from a water-saturated substrate in which the oxygen conditions had been depleted or in which carbon dioxide or hydrogen sulfide had accumulated. However, they can live for long periods in aerated water, such as in trickling filters in wastewater treatment plants (EDWARDS, 2004). SHERMAN (2003) showed that, earthworms can survive in relatively low oxygen and high carbon dioxide environments and even stay alive when submerged in water if it contains dissolved oxygen. Oxygen may be depleted if earthworm beds are kept too wet or if too much feed is introduced. By reducing the amount of moisture, cutting back on feed, and turning the pile with a pitchfork or three-prong garden tool, oxygen will be restored.

2.4.2.4. Temperature

Earthworms have fairly complex responses to changes in temperature. Most earthworm species used in vermicomposting require moderate temperatures from 10- 35° C while tolerance and preference vary from species to species. Earthworms can tolerate cold and moist conditions far better than hot and dry conditions (SHERMAN, 2003). EDWARDS (1988) studied the life cycles and optimal conditions for survival and growth of *E. fetida, D. veneta*. Each of these two species differed considerably in terms of response and tolerance to different temperatures. The optimum temperature for *E. fetida* was 25° C, and its temperature tolerance was between 0 and 35° C. *D. veneta* had a rather low temperature optimum and rather less tolerance to extreme temperatures. EDWARDS (2004) reported that, The unfavorable effect of high temperatures (above 30° C) on most species of earthworms is not entirely a direct effect because these warm temperatures also promote chemical and microbial activities in the substrate, and the increased microbial activity tends to consume the available oxygen, with negative effects on the survival of earthworms. The major drawback of the vermicomposting process is that the temperature is not high enough for an acceptable pathogen kill (unlike the thermophilic composting methods), as it must be maintained at less than 35° C during the vermicomposting processes (MISRA et al., 2003).

2.4.2.5. Vermicompost reaction (pH)

Most species of epigeic earthworms are relatively tolerant to pH, but when given a choice in the pH gradient, they moved toward the more acid material, with a pH preference of 5.0 (EDWARDS, 2004). However, earthworms will avoid acid soils of pH less than 4.5, and prolonged exposure to such soils could have lethal effects (EDWARDS & BOHLEN, 1996). Minor increases in acidity caused by addition of fresh wastes to the vermicomposting bed can be neutralized by the intestinal calcium secretions of earthworms and excreted ammonia. Lime is commonly added to vermicomposts. In another study, worms can survive in a pH range of 5 to 9, but a range of 7.5 to 8.0 is considered to be the optimum (EDWARDS, 1998).

2.4.2.6. Pre-composting of organic waste

GUNADI and EDWARDS (2003) reported the death of *Eisenia fetida* after 2 weeks in the fresh cattle solids although all other growth parameters such as moisture content, pH, electrical conductivity, C:N ratio, NH_4 and NO_3 contents were suitable for the growth of the earthworms. They attributed the deaths of earthworms to the anaerobic conditions which developed after 2 weeks in fresh cattle solids. It is established that pre-composting of organic waste is very essential to avoid the mortality of worms. However, organic wastes that have too much ammonia became acceptable after the ammonia was removed by a period of composting or when both excessive ammonia and salts were washed out of the waste (EDWARDS, 2004).

2.4.3. Types of vermicomposting systems

According to TENZIN (2002) the following are the suggested systems for vermicomposting

2.4.3.1 Windrows

This system takes into account the availability of large land and other appropriate technology for operating the whole system. These systems are extensively being used for used both in the open and under cover. Windrow vermicomposting can be carded out in a number of different ways. The two most common types of windrow are static pile windrows (batch) and top-fed windrows (continuous flow).

2.4.3.2 Wedge system

This is a modified type of windrow system where one can easily harvest the vermicompost without disturbing the earthworms. In this system organic materials are applied in layers against a finished windrow at a 45° angle. The pile can be inside a structure or outdoors if they are covered with a trap or compost cover to prevent the leaching of nutrients.

2.4.3.4 Bed and bin system

Here in this system bins are used to breed and harvest the vermicompost and also in some case beds are made on the ground for the same purpose. This method is labor intensive but is much easier to handle and is widely. The two most common types of bed and bin system are top-fed beds (continuous flow) and stacked bins (batch or continuous flow).

2.4.3.5 Reactor system

Reactor systems have raised beds with mesh bottoms. Feedstocks are added daily in layers on top of the mesh or grate. Finished vermicompost is harvested by scraping a thin layer from just above the grate, and then it falls into a chamber below. These systems can be relatively simple and manually operated or fully automated with temperature and moisture controls. For maximum efficiency, they should be under cover.

Factors that may be considered for selecting the appropriate vermicomposting technology for a project include: Amount of feedstock to be processed; Funding available; Site and space restrictions; climate and weather; state and local regulatory restrictions; facilities and equipment on hand; and availability of low-cost labors etc.

2.4.4. Classification of earthworm

Earthworms are terrestrial invertebrates with thousands of species grouped into three categories according to their behavior in the natural environment (GAJALAKSHMI& ABBASI, 2004; VINOD et al., 2008): anecic, endogeic, and epigeic.

Anecic species, represented by the common nightcrawler (*Lumbricus terrestris*), construct permanent vertical burrows as deep as 4 to 6 feet in the soil. They feed on organic debris on the soil surface and convert it into humus. If anecic species are deprived of their permanent homes, they will discontinue breeding and cease to grow.

Endogeic species, such as *Aporrectodea calignosa*, build wide-ranging, mainly horizontal burrows where they remain most of the time, feeding on mineral soil particles and decaying organic matter. They are the only species of earthworms that actually feed on large quantities of soil. As they move through the soil and feed, they mix and aerate the soil and incorporate minerals into the topsoil.

Epigeic species, represented by the common redworm (*Eisenia fetida*), do not build permanent burrows; instead, they are usually found in areas rich in organic matter, such as the upper topsoil layer, in the forest under piles of leaves or decaying logs, or in piles of manure. Since they don't burrow deeply into the soil and prefer to eat rich organic matter, epigeic worms adapt easily to vermiculture and vermicomposting systems. *Eisenia fetida* and *Eisenia hortensis (Dendrobaena veneta)* constitute about 80 to 90 percent of the earthworms raised on a large-scale commercial basis. For the purpose of vermicomposting of different organic wastes, generally epigeic species of earthworms are used widely in India (ISMAIL, 2005).

According to their feeding habits, earthworms are classified into detritivorous and geophagus (LEE, 1985). ***Detritivores*** feed at or near the soil surface mainly on plant litter or dead roots and other plant debris in the organic matter rich surface soil or on mammalian dung. These include epigeic and anecic forms. These are also called as humus formers. ***Geophagus*** feed deeper beneath the surface, ingesting large quantities of organically rich soil. These include endogeic forms. These are also called as humus feeders. In deep, earthworm species used in the current study are characterized as follow:

Eisenia fetida

The species most commonly used for breaking down organic wastes is *E. fetida.* There are a number of reasons why these species are preferred in vermicomposting all over the world. They are peregrine species that are very common, and many organic wastes became colonized naturally by this specie. It has a wide temperature tolerance and can live in organic wastes with a range of moisture contents. It is tough earthworm, readily handled, and in mixed species cultures they usually becomes dominant, so that even when vermicomposting systems begin with other species, they often end dominated by *E. fetida*. Under optimal conditions, their life cycles, from freshly deposited cocoon through sexually mature clitellate earthworm and the deposition of the next generation of cocoons, range from 45 to 51 days. The time for hatchlings to reach sexual maturity ranges from 21 to 30 days. Cocoon laying begins 48 hours after copulation, and the rate of cocoon production is between 0.35 and 1.3 per day. The hatching viability is 72 to 82 %, and the incubation period ranges from 18 to 26 days. The number of young earthworms hatching from each viable cocoon varies from 2.5 to 3.8 depending on temperature. Maximum life expectancy is 4.5 to 5 years, but the average life survival was 594 days at 28° C and 589 days at 18° C, although under natural conditions it may be considerably less than these figures because they have so many predators and parasites in the wild (EDWARDS & BOHLEN, 1996).

Dendrobaena veneta

Dendrobaena veneta is a robust earthworm that can tolerate much wider moisture ranges than many other species and has a preference for mild temperatures (15 to 25° C). Its life cycle can be completed in 100 to 150 days, and 65 days is the average time to reach sexual maturity. Mean cocoon production has been reported as 0.28 per day, but the hatching viability is low (20 %), and the mean cocoon incubation period is 42 days. The mean number of earthworms hatching from each viable cocoon was about 1.10 (MUYIMA et al., 1994). From The Influence of Temperature on the Life-Cycle of *D. veneta*, at 15° C the life-cycle was completed in 100 days and it took 150 to complete the cycle at 25° C. At 25° C maturation was quicker, worms started to produce cocoons at a younger age and more cocoons were produced (per worm, per day) than at 15° C. The incubation period and the number of hatchlings per cocoon were more at the lower temperature (VILJOEN et al., 1992). The researchers found *D. veneta* to be a large worm with a low reproductive rate and slow maturity rate compared to *E. fetida*. Observations of small-scale vermicomposting and vermiculture systems using mixed cultures of *E. fetida* and *D. veneta* show that *E. fetida* tends to remain in the upper, dryer regions of the bin and *D. veneta* to populate the lower bedding areas where moisture concentrations are highest (EDWARDS, 1988; NEUHAUSER et al., 1988).

2.5. Integrating composting and vermicomposting process

The major drawback in the vermicomposting process is that it must be maintained at temperatures below 35° C and exposure of worms to temperatures above this will kill them. Perhaps the greatest challenge to vermicomposting is to assure that the feedstocks do not attain a temperature high enough to begin the thermophilic process of decomposition, as this would kill the worms (NATHAN, 2004). The vermicomposting process temperature is not high enough for acceptable pathogen kill and hence the product does not pass EPA (Environmental Protection Agency) rules for pathogen reduction. In addition, the major problems associated with thermophilic composting are the long duration of the process, loss of nutrients during the prolonged composting process and the frequency of turning of the material (ALIDADI et al., 2005).

An integrated system from both the thermophilic composting process and the vermicomposting process would be necessary to provide a product free of pathogens, and product with desirable characteristics at a faster rate than either of the individual processes. In England, (LOGSDON, 1994) reported successful addition of worms after the heat of the initial decomposition subsides. The worms worked well in this situation and shortened the time for curing and stabilization of the compost. Furthermore, combining composting with vermicomposting also accelerated the composting process thus reducing the time required for composting (NEDGWA & THOMPSON, 2001). The combined approach suggested by ALIDADI et al. (2005) was a vermicomposting and combined compost vermicomposting processes of sludge. The sludge mixed with sawdust to provide C:N ratio of 25:1. *Eisenia fetida* was the species of earthworms used in the vermicomposting processes. The result obtained indicates reduction in the amount of volatile solids, total carbon and C:N ratio with the vermicompost age, which indicates the reduction in the biodegradable organic content and mineralization of sludge. Also increase in phosphorus concentration by the end process because of mineralization of organic matter. The results indicate that, a system that combines the two mentioned processes not only shortens stabilization time, but also improves the products quality. Combining the two systems resulted in a product that was more stable and homogenous; the product could meet the pathogen reduction requirements. HASSOUNEH et al. (1999) reported that, combined compost vermicomposting process is more efficient in stabilizing sludge than the vermicomposting process.

FREDERICKSON et al. (1997) investigated the sustainability of a combined system comprising traditional windrow composting followed by vermicomposting and recommended minimizing composting duration to maintain high earthworm populations. TOGNETTI et al. (2005) studied end product quality for a combined system which involved thermophilic composting of mixed municipal waste followed by either windrow composting or vermicomposting. There is growing interest in the use of combined composting systems, which include vermicomposting, that are designed to achieve specific technical objectives, such as producing high specification composts or to comply with environmental legislation. In another study, TOGNETTI et al. (2007) mentioned that, vermicomposting of previously composted material led to products richer in organic matter, total nitrogen, and available nutrient concentrations than composting only, probably due to the coupled effect of earthworm activity and a shorter thermophilic phase. FREDERICKSON et al. (2007) determine the effect of thermophilic pre-composting followed by vermicomposting on compost characteristics compared with thermophilic pre-composting and windrow composting of household waste. Results observed that, significantly greater mass ($P < 0.01$) of fine particles (<10 mm) in the vermicomposting beds (65.3 %) compared with the compost windrows (36.9 %)

suggesting enhanced fragmentation of the paper-based feedstock components by the earthworms. The vermicompost NO_3 concentration (2660 mg kg^{-1}) was significantly higher ($P < 0.05$) than for the windrow compost (1531 mg kg^{-1}).

2.6. Physico-chemical changes during composting processes

2.6.1. Temperature cycle

During aerobic decomposition of organic substances, the chemical energy in the material is either released as heat or used for the construction of new substances within the organisms consuming the organic material. Based on microbial activity, the composting process can be divided into four different stages (Fig 2.3). The first stage is the mesophilic stage, where the predominant microbes are the mesophilic bacteria. The abundance of substrate at this time ensures that the microorganisms are very active, leading to the generation of large quantities of metabolic heat energy, which causes the temperature of the compost pile to increase. According to MICHAEL and KATHLEEN (2001), the microbial activity in the 35 to 45° C range is prodigious.

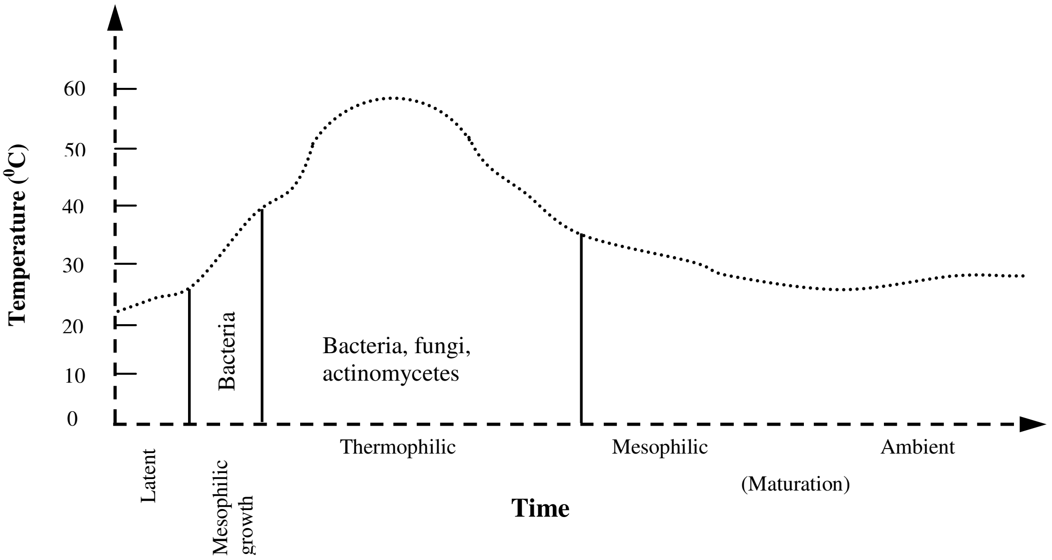

Fig. 2.3: Patterns of temperature and microbial growth in compost piles (after MICHAEL & KATHLEEN, 2001)

As the temperature rises past 45° C, conditions are less favorable for the mesophilic bacteria and instead begin to favor the thermophilic bacteria. The resulting increased microbial activity of the thermophilic causes the temperature in the compost pile to rise to 65 to 70° C (NATHAN, 2004; EILAND et al., 2001). Eventually, with the depletion of the food sources, overall microbial activity decreases and the temperature falls resulting in a second mesophilic phase during the cooling stage. As the readily available microbial food supply is consumed, the temperature falls to ambient and the material enters the maturation stage. Microbial activity is low during this stage (BURFORD, 1994; MICHAEL & KATHLEEN, 2001). LIANG et al. (2003) found that as long as compost temperatures were maintained above 40° C, no significant improvements of composting rates were achieved at higher temperatures.

2.6.2. Carbon, nitrogen, C:N ratio, pH and CO_2 dynamics

EILAND et al. (2001) noted that total C concentrations remained constant during the initial mesophilic phase until temperatures peaked 70° C in a mixture of pig (*Sus scrofa domesticus*) manure and Miscanthus (*Miscanthus* spp.) straw, decreasing over 10 to 50 days from 40 to 69 % of initial levels. Lignin fractions were not degraded by composting periods of 65 and 70 days. Hemicellulose concentrations, on the other hand were reduced to 6 % of initial levels over the composting period. In contrast, cellulose concentrations remained constant until day 8, then decreased and stabilized by day 50 at 30 to 36 % of initial levels. Both cellulose and hemicellulose fractions remained constant during the first week of thermophilic composting until soluble C was metabolized by microbes. SUTHAR (2006) has reported that earthworms promote such microclimatic conditions in the vermireactors that increase the loss of organic carbon from substrates through microbial respiration. GARG et al. (2005) have reported a 58.4 % reduction in organic carbon in cow dung and 55.4 % reduction in horse dung after 90 days of vermicomposting. KAVIRAJ and SHARMA (2003) have reported a 20-45 % loss of organic carbon during vermicomposting of municipality or industrial wastes.

Nitrogen dynamics during composting are largely related to microbial activity. Most N in composting substrate is in the organic form. During the initial rise in temperature, heterotrophic microbes attack the amine groups present in organic matter as humus or proteins, forming amino compounds. Following hydrolization, N is either released as ammonium (NH_4^+) or is immobilized by other microorganisms and returned to its organic form (EILAND et al., 2001; NATHAN, 2004). When substrate temperatures exceed 40° C or if pH rises above 7.5, N generally volatilizes as ammonia (NH_3^+). Nitrate (NO_3^-) concentrations in the compost substrate are low during this thermophilic phase due to O_2 consumption by the nitrifiers. During mineralization, hydrogen ions are consumed or lost as water, thereby lowering the pH of the substrate. Mineralization of organic N slows in the latter phases of composting as remaining ammonium is consumed; resulting in increases of nitrate concentrations (SANCHEZ-MONEDERO et al., 2001).Vermicomposting process causes significant increase in total nitrogen content of feed stocks after worm activity. According to NATHAN (2004) nitrogen content in vermicompost is dependent on the initial nitrogen present in the feedstock and the degree of decomposition. Addition of nitrogen in the form of mucus, nitrogenous excretory substances, growth stimulating hormones and enzymes from earthworms has also been reported (TRIPATHI & BHARDWAJ, 2004). These nitrogen rich substances were not originally present in feed and might have contributed additional nitrogen content.

The ratio of C:N ratio of the finished compost to the C:N ratio of composting mix initially is about 0.65 to 0.75 (ARJA & MARITTA, 1997). This indicates that the C:N ratio of the initial composting mix will be reduced by 25 to 40 % under normal composting conditions. Final compost with a C:N ratio greater than 20 should be avoided since it could have a negative impact on plant growth and seed germination. However, it is the availability of the C that is important, not the total measured C, so composts with C:N ratios higher than 20 can be acceptable when the C is not readily available (MICHAEL & KATHLEEN, 2001; TIQUIA et al., 2002).

As microbial metabolism of readily soluble carbon (sugars, carbohydrates, hemicellulose and cellulose) in the compost feedstock increases, more oxygen is consumed and carbon dioxide released (EPSTEIN, 1997; EILAND et al., 2001; DRUILHE et al., 2002). Once labile C is degraded, microbial activity slows and CO_2 decreased; the majority of the remaining carbon is in the form of lignin or cellulose. Because lignin is the carbon compound that is most recalcitrant to degradation, substrates with high lignin content are not quickly composted (NATHAN, 2004).

The pH value changes during composting, due to changes in the chemical composition (Fig 2.4). In general, the pH falls below neutral in the beginning due to the formation of organic acids and later rises above neutral because the acids are consumed and because ammonia is released (BECK-FRIIS et al., 2003; SUNDBERG, 2005). During vermicomposting usually pH decreases from alkaline to acidic or neutral pH (GARG et al., 2005). The pH shift towards acidic conditions has been attributed to mineralization of the nitrogen and phosphorus into nitrites/nitrates and orthophosphates; bioconversion of the organic material into intermediate species of organic acids (NDEGWA et al., 2000). Differences in physico-chemical properties of organic wastes could result in the production of different intermediate species and so different wastes show a different behavior in pH shift.

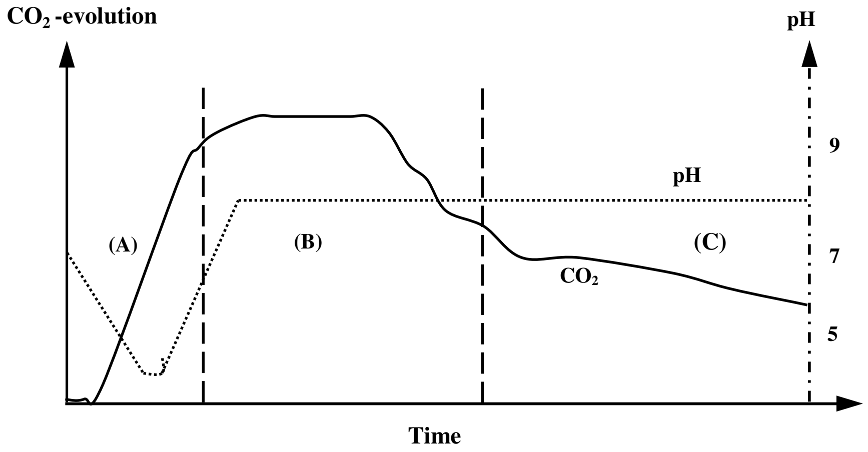

Fig. 2.4: A representation of a typical pH curve in a batch composting process (after SUNDBERG, 2005)
(A) Initial phase
(B) High-rate phase
(C) Curing phase

2.6.3. Humic substances

A reduction of carbohydrate, hemicellulose, and cellulose during the composting process is accompanied by increased humification. Accompanying with increase in humification is increases of alkyl C, aromatic C, and carboxyl (-COOH), phenolic (-OH), and cabonyl (-CO) groups. The aromatic and phenolic C containing groups increased by 23 and 16 %, respectively, following composting of municipal solid waste (CHEFETZ et al., 1998). The other major changes in the characteristics of compost are the marked increase in the content of humic acids and consequently the cation exchange capacity of compost (INBAR et al., 1989), which appear to follow the first-order kinetics. Because of increased aromatic nature of composting product, composting process influenced not the elemental composition of finished compost but the functional groups (SANCHEZ-MONEDERO et al., 2002). Questions arise as to the origin of humic substances from the composting. ADANI et al. (1999) indicated that no net humic substances were formed during composting. This is in line with the findings that humic substances in the compost retain structural characteristics of lignin in the wood waste or crop residue used as bulking agent, and increased aromaticity of humic acids result as the protective coating materials (polysaccharides, polypeptides, and lipids) are degraded (CHEFETZ et al., 1998). However, other investigators (GONZALEZ-VILA et al., 1999) found that humic substances production is increase with increasing composting period.

2.7. Indices of compost and vermicompost stability and maturity

Compost stability and maturity indexes, however, are generally not regulated. Compost stability refers to the resistance of compost organic matter to further rapid degradation. Compost maturity is related to suitability for plant growth, although some authors also relate it to humification (TOMATI et al., 2000; SULLIVAN & MILLER, 2001). During the last two decades scientists have been looking for reliable parameters to determine compost maturity, for example, plant growth, respiration rates, humification index, and C/N ratio (LAOS et al., 2002; RYNK, 2003). In fact the use of unstable/insufficiently mature manure could potentially damage both soils and crops (ALICE et al., 2008). A number of methods to test compost stability and maturity have been proposed over the last two decades with varying degrees of sophistication (WU et al., 2000). The rate of the release of the decomposition products (CO_2) and the rise of temperature of composting mix are related to compost stability, whereas the biological response to compost is related to compost maturity. All these methods are listed on Table 2.1 (KUO et al., 2004).

Table 2.1: Methods for predicting compost stability and maturity

Methods	Parameter
Physical analysis	Temperature, color
Chemical analysis	NO_3-N, NH_4-N, waster-soluble C, C:N ratio, cation exchange capacity, Humic and fulvic acid
Microbiological assays	Respiration (CO_2 evolution; O_2 consumption)
Plant assays	Cress germination test in water extract, ryegrass growth in compost containing mixtures
Spectroscopy analyses	Solid state CPMAS ^{13}C-NMR, infrared- FTIR

2.7.1. Temperature

As heat is released during microbial degradation of organic matter, temperature of composting mix is a good indicator of its stability. The Dewar Test (BRINTON, 2000)) is often employed for the determination of compost self-heating. When the increase above ambient temperature from self-heating is less than 10° C, the compost is classified as completely stable (Table 2.2). As self-heating intensifies by the further rise in temperature above ambient, the compost is increasingly immature. Being simple and easy to use, Dewar Test is used by many composting facilities around the world. A rise in compost temperature to a pre-determined maximum above ambient conditions constitutes an immature compost (BARI et al., 2000).

Table 2.2: Dewar self-heating test and CO_2 loss for determining the compost maturity (USDA, 2000)

Heating rise over ambient	CO_2 loss [mg g^{-1} C d^{-1}]	Rating	Description of stability
0 to 10	0 to 2	V	Completely stable, can be stored
10 to 20	2 to 8	IV	Maturing compost, can be stored
20 to 30	8 to 15	III	Material still composting, do not store
30 to 40	15 to 25	II	Immature, active composting
40 to 50	> 25	I	Fresh, very active composting

2.7.2. Microbial respiration rate (CO_2)

Associated with a rise in microbial activity is the release of CO_2 and consumption of O_2. The respiration rate in C loss $g^{-1}d^{-1}$ at 34° C has been used in defining the class of compost (Table 2.2). A low respiration rate is indicative of high compost stability. However, a low respiration rate of compost may not necessarily be a good indication that phytoxicity would not occur (KUO et al., 2004). This is particularly the case when microbial activity is inhibited by high metal concentration. WU et al. (2000) found that compost samples from one composting facility showed phytotoxicity despite having a low CO_2 evolution rate. Microbial respiration, as measured by O_2 uptake and CO_2 production, generally decreases with the loss of readily biodegradable carbon and the subsequent stabilization of the remaining fractions. BREWER and SULLIVAN (2002) reported high respiration rates during the first 27 days of aerated yard waste compost, and stable respiration during the curing period of 70 to 133 days. BELETE et al. (2001) estimated microbial respiration in a forced-aeration windrow of household and yard waste compost bulked with woodchips; they found a significant correlation between compost age and decrease in microbial respiration.

2.7.3. Total carbon, total nitrogen and C:N ratio

Carbon to nitrogen ratio is one of the parameters used as an index of compost maturity. As composting proceeds, a greater C than N loss results in the reduction of C:N ratio (KUO et al., 2004). When C:N ratio reaches below 25:1, composting is generally considered to be mature. Despite a close relationship between the change in C:N ratio and the change in CEC or in the concentration of humic acids, C:N ratio alone is not a good index of maturity of composts made from a diversity of waste streams and bulking agents. For characterization of compost maturity, C:N ratio should be used in conjunction with other stability indexes. In the California compost quality council (FUELEKY & BENEDEK, 2010), the compost is deemed mature if C:N ratio is ≤ 25 and the oxygen uptake rate is ≤ 150 mg O_2 kg^{-1}. Equally difficult to correlate with compost maturity is the reduction in the carbon to nitrogen (C:N) ratio. C:N is measured either in solid compost or a compost water extract. The N concentration in mature compost is generally very low and the C:N in compost is generally higher in the solid compost than in the water extract (EGGEN & VETHE, 2001). Other research has correlated C:N with other stability indices (EILAND et al., 2001; LAOS et al., 2002; RYNK, 2003). While the C:N ratio will vary depending on the compost feedstock, C:N ratios less than 12 are often considered stable (BERNAL et al., 1998). INBAR et al. (1990) traced the C:N ratio of the solid phase, typically beginning at 40:1 before dropping quickly at first, then slowing, to finish at about 18:1. During the composting process, the TN gradually increased due to the mineralization of organic matter and simultaneously the TOC were decreased due to the humification through the degradability of the organic carbon. Also, the TOC decreased due to mineralization of carbonic materials (EGHBALL et al., 1997). These processes minimize the difference between C and N and finally the C:N ratio decreased (HELLAL, 2007). The increase in TN of different composted materials may be due to concentration effect because of bio-oxidation of OC during composting. In this respect, KHATER et al. (1997) reported that the increase in TN during composting may be due to the higher oxidation of non-nitrogenous organic materials and partially to the N_2 - fixation by non-symbiotic nitrogen fixers as indexed by the increase in organic nitrogen.

2.7.4. Thermogravimetric analysis

Physical techniques such as thermogravimetric analysis have also been applied to assess compost biostabilisation; for this technique a small sample is sufficient, it does not require chemical extraction and is easy to reproduce (DELL'ABATE et al., 2000; MONDINI et al., 2003). ALICE et al. (2008) study the maturity levels in manure from laying hens by using both chemical (dry matter, ashes, carbon and its fractioning, total and ammoniacal nitrogen) and physical methods, such as thermogravimetry. From a statistical point of view, chemical methods are effective only in distinguishing among different drying methods connected with manure management systems. Only thermogravimetric analysis can identify mature samples by means of total mass loss in the range RT- 900° C, mass loss in the range 350-425° C and energy release at 500°C. In addition, thermogravimetric profiles could be used to define a fingerprint for this kind of biomass. Thermogravimetry has been used to assess compost stability and maturity, which undergo transformations at different temperatures, produce a graph whose shape reflects the chemical composition and structure of the sample (MONDINI et al., 2003; BAFFI et al., 2007).

Thermogravimetry (TG) and differential thermal analysis (DTA) methods are based on programmed heating of the sample in a controlled atmosphere. During thermogravimetric analysis (TGA), the weight change in a sample is measured during the thermal program. The first derivative of the TG trace represents the weight loss rate DTG (expressed as % min^{-1}). Most analysis in DTA is carried out between ambient temperature a difference in temperature is observed between the sample and the reference (Fig. 2.5 and Eq. 2.1) and according to (PANSU & GAUTHEYROU, 2006):

$$\Delta T = T_{sample} - T_{reference} \qquad \text{Eq. 2.1}$$

– If the temperature is lower than that of the inert reference material, an endothermic peak appears (ΔT is negative), this is the case in reactions of dehydration, dehydroxylation, fusion, evaporation, sublimation, etc.

– If, on the contrary, the temperature of the sample exceeds that of the reference, an exothermic peak appears (ΔT is positive), this is the case for oxidation phenomena (combustion of OM, oxidation of sulphides, oxidation of ferrous iron, certain nucleations or decomposition with neoformation.

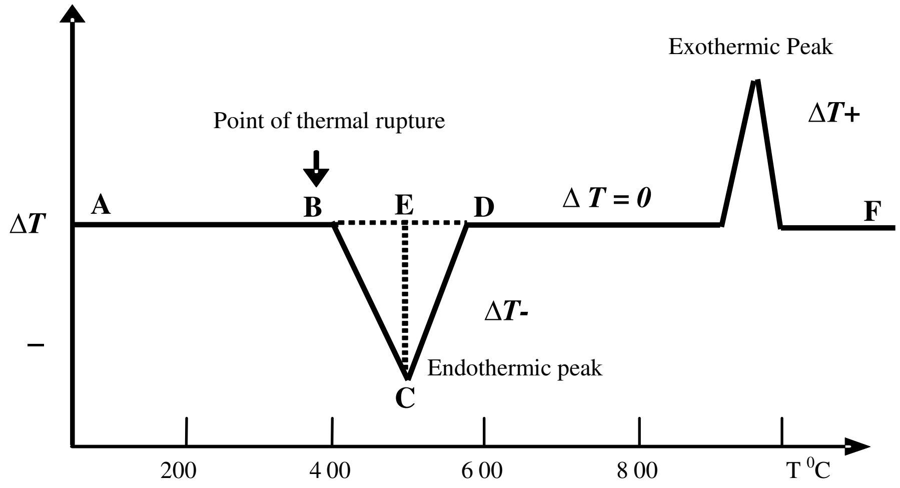

Fig. 2.5: Diagrammatic output of differential thermal analysis

BD = peak width EC = peak height
BCD = peak surface AF = base line.

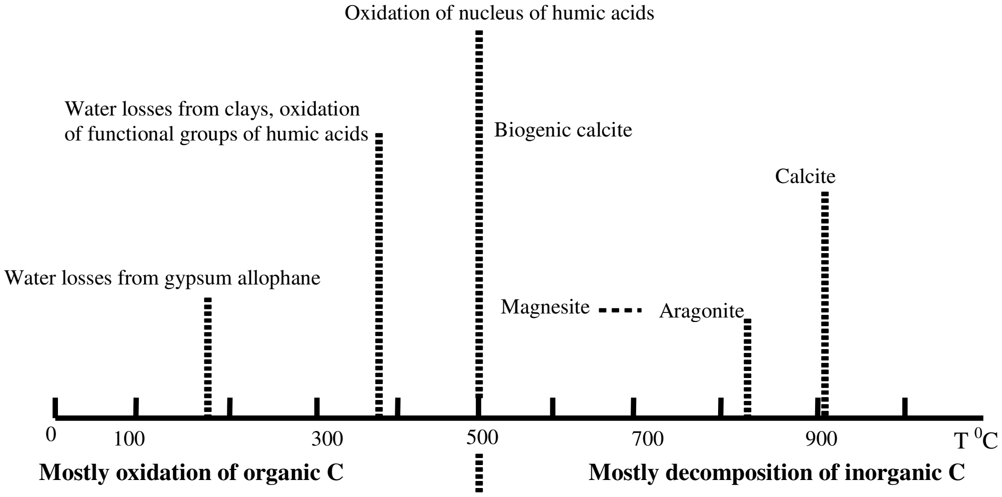

Fig. 2.6: Oxidation of organic C and decomposition of inorganic C as a function of temperature

Contrary to TGA, DTA can produce peaks even if there is no loss or increase in weight. The shape, size and temperature of the peaks are influenced by instrumental factors such as the speed of heating, the nature of the sample support and of the thermocouples. Small samples give a better resolution of the peaks and allow faster heating. Slower speed can increase sensitivity, but to the detriment of temperature, precision, and resolution. A dynamic atmosphere is preferable to a self-generated static atmosphere. This allows continuous evacuation of evolved gas, thus reducing the risks of artifact reactions at higher temperatures. These gases can then be analyzed enabling identification of the molecular structure of the compounds that caused the gaseous emission (PANSU & GAUTHEYROU, 2006). The sum of the different carbon phases gives total C; and it is possible to roughly separate total organic C and total inorganic C are shown in fig 2.6.

2.7.5. Humic substances and humification parameters

As the compost process is ultimately one of stabilization that incorporates the production of humus, the degree of organic reconstitution, or humification, is frequently considered as the most appropriate indicator of compost stability (CIAVATTA et al., 1993). Humification is the biochemical process promoting the chemical re-synthesis and re-polymerization of moieties produced from the decomposition of fresh organic material producing aromatic and aliphatic macromolecules. CHEN et al. (1996) evaluated the stability of a number of composts in terms of humic substances comprised of fulvic acid (FA), humic acid (HA), and the non-humified fraction. In general, there was an increase in humic acid as a percentage of organic matter in the humification ratio. Figure 2.7 indicates typical trends in maturity criteria over time based on organic acids, organic carbon and the C:N ratio. The humic acid concentration increases and depends upon the nature of the substrate and the composting technique as noted by WITTER and LOPEZ-REAL (1987). These authors reported that, the humic acid concentration of fresh uncomposted material ranged from 2.3 %–25.2 %. ADANI et al. (1999), however, found that there was a net reduction of humic substances in four composting processes if the absolute content was considered. The authors suggest the presence of a nucleus of humic acids or "core humic acid" coated with core degradable organic molecules consisting of lipids, proteins and carbohydrates called "interference material". The degradation of the interference material did not support the net increase of humic substances. Their work in concluding that humification does not take place, underscores the need to review the humic extraction technique as a reliable measure of compost stability. EGGEN and VETHE (2001) also correlated total organic carbon in the fulvic fraction to microbial respiration. As compost stabilizes the ratio of humic to fulvic acids (humification) increases, due to loss of readily degraded fulvic acids (BERNAL et al., 1998).

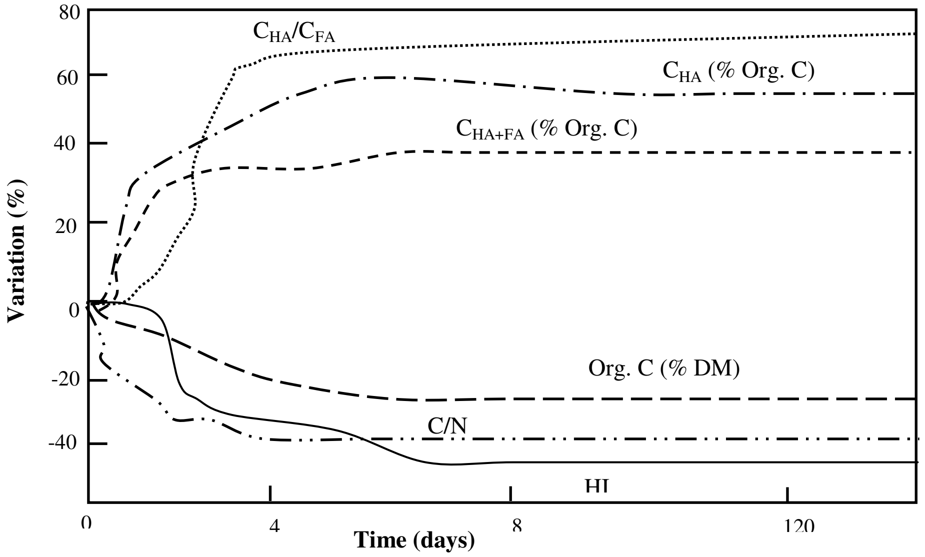

Fig. 2.7: Typical trends in maturity criteria over time (after CHEN et al., 1996)

Depending on the released amount of HA and FA, the parameters usually used to determine the maturity of compost are degree of humification (DH), humification rate (HR), and humification index (HI). In most compost materials due to decomposition and mineralization of organic substances both DH and HR increased during composting process while HI was decreased (CIAVATTA et al., 1993). The DH, HR and HI have been demonstrated to be effective in quantitatively evaluating the humic substances formation during compost maturation and to establish with accuracy the time of its complete stabilization (MARIA et al., 1998). Decreased HI to 0.37 in the final composts indicating that, the final composts is well humified whereas the DH values were higher than 80 % (MONDINI et al., 2003).

2.8. Physical and chemical properties of compost and vermicompost

2.8.1. Physical properties

Moisture is most often expressed as a fraction of total compost weight. As moisture content increases, dry matter per unit weight decreases. Moisture content may also provide some understanding of processing or storage conditions. Composts with moisture contents of less than 35 % may not have been fully stabilized due to low moisture, or may have been stored for excessively long periods leading to moisture loss. Composts with less than 35 % moisture are often dusty and unpleasant to handle (SULLIVAN & MILLER, 2001). Vermicompost produced from most organic wastes is usually had excellent structure, porosity, aeration, drainage, and moisture-holding capacity (EDWARDS, 2004). Most composts with an as-is moisture content of 35 to 55 % will have a bulk density of 500 to 700 kg m^{-3}. Bulk density on a dry weight basis is an indicator of particle size and ash content. Dry bulk density usually increases with composting time as ash content increases and as particle size is reduced by decomposition, turning, and screening (RAVIV et al., 1987). As bulk density increases, drainage and air-filled porosity of growing media are reduced, and water holding capacity is increased. The final percentage of particles less than 5 mm in size is greatly increased by the vermicomposting process (NATHAN, 2004).

In vermicomposting, the relatively quick fragmentation of particulate matter is achieved by the grinding muscular gizzard of the worm with the help of enzymatic secretions such as amylase, cellulase, protease, lipase, chitinase, and lichenase (NATHAN, 2004). Also, the presence of certain actinomycetes aids the formation of clay-humic complexes and other cementing agents (SENAPATI, 1993). The result is a loosely aggregated, granular material whose stability depends on organic matter and moisture concentrations and bacterial and fungal polysaccharides structure.

2.8.2. Chemical properties

WARMAN and ANGLOPEZ (2002) reported increases in CEC from 45 to 80 cmol kg^{-1} after 90 days of vermicomposting kitchen + yard waste. NATHAN (2004) suggested that, High humic fractions can result in increased CEC in waste processed with worms. ALBANELL et al. (1988) reported a greater CEC (17 %) in vermicomposted sheep manure + cotton waste compared composted feedstock after 12 weeks. Similarly, humic acid concentration was 31 % greater in vermicompost than in compost. The pH range for most finished composts is from 6.0 to 8.0. Most of the literature attributed this neutralization to humification of the substrate. The final pH of the compost is highly dependent on the feedstock, the compost process, and the addition of any amendments. Compost feedstocks such as wood may be quite acidic, while others (e.g., lime-treated biosolids) may be a significant source of alkalinity (SULLIVAN & MILLER, 2001). In potting media, compost pH can be increased by lime addition, and reduced by elemental sulfur (S) addition. The vermicomposting process generally neutralizes the pH of the substrate. This may be attributed to $CaCO_3$ secretions in the worm gut that have an alkalizing effect on the feedstock (BUCHANAN et al., 1988; SENAPATI, 1993). Most compost contains a significant amount of nutrients in the form of fertilizer salts. These fertilizer salts are also referred to as soluble salts. A good rule of thumb is if the compost has a soluble salt content above 5.0 dS m^{-1}, then no greater than a 20 % inclusion rate of compost should be used (GOUIN, 1997). Soluble salts and electrical conductivity (EC) generally increase over the course of the vermicomposting (KALE, 1998; MASCIANDARO et al., 1997), but WARMAN and ANGLOPEZ (2002) reported an eventual decrease in electrical conductivity, supporting the earlier findings of ELVIRA et al. (1998).

Compost products contain a considerable variety of macro- and micronutrients. Although often seen as a good source of N, P, and K, compost also contains sulfur (S), calcium (Ca), and magnesium (Mg), as well as micronutrients essential for plant growth. Because compost contains relatively stable sources of organic matter, these nutrients are supplied in a slow-release form. Compost made from biosolids often has a higher N and P concentration than compost made from animal manures and yard trimmings (ALEXANDER, 2001). NDEGWA et al. (2000) reported that while N concentration did not change during vermicomposting, total N reductions paralleled decreases in total solids, and they concluded that N was either volatilized or taken up in the worms' tissue. In contras, ELVIRA et al. (1998) reported 55 to 100 % increases in total Kjeldahl's N (TKN) concentrations due to mineralization of organic matter. Similarly, WARMAN and ANGLOPEZ (2002) observed 42 to 85 % increases in total N in three vermicomposted wastes after 45 and 68 days. After 90 days, however, total N concentration had returned to levels only slightly above initial concentrations of 13, 24, and 20 g kg^{-1}. Phosphorus concentrations in composts generally range from < 0.4 to >23 g kg^{-1} (HE et al., 1995; VOGTMANN et al., 1993), depending on sources. Biosolids generally contain a greater P concentration than most feedstocks. However, a varying proportion of P in biosolids is in organic forms, which are less available to plants (HE et al., 2000). This P concentration is about 2 to 10 times greater than the total P (0.2 to 2.0 g kg^{-1}) in most agricultural soils (HE et al., 2001). Organic P in composts from plant materials is readily decomposed to release ortho-phosphate, which is available to plants. The availability of P in composts ranges from 20 to 40 % of the total P content (VOGTMANN et al., 1993). The concentrations of K in composts vary from 0.7 to >12 g kg^{-1}, with a mean of 5.4 g kg^{-1} (HE et al., 2001). Potassium is highly mobile in plants at all levels within individual cells and within tissues (MARSCHNER, 1995). Therefore, part of the K in plant materials may be lost during composting. Composts can be an alternative source of K for crops. Plant availability of K in composts can be more than 85 % of the total K content (VOGTMANN et al., 1993). Calcium concentrations in composts vary from 21 to 75 g kg^{-1}, with a mean of 39 g kg^{-1}. The forms and availability of Ca depend on the source and feedstock composition of the compost. Composts contain Mg concentrations in the range of 1 to 5 g kg^{-1}, with a mean of 3.5 g kg^{-1} (HE et al., 2001).

Composts contain variable amounts of micronutrients. Total Fe concentration in composts is from 2000 to 16,000 mg kg^{-1}. Biosolids have a relatively high concentration of Fe, but water solubility of Fe is low (insoluble forms of Fe are dominant) (HE et al., 2000). Composts made from MSW generally contain less Fe than those made from biosolids. The availability of Fe is very low in biosolids and the amount of Fe extractable by the Mehlich 3 reagent accounts for less than 1 %. Copper concentrations in composts range from 43 to 630 mg kg^{-1} based on data from the U.S. and some European countries. This concentration range is about 4 to 50 times greater than the mean value of total Cu in the world soil (12 mg kg^{-1}) (BERROW & REAVES, 1984). However, Cu in composts is generally chelated by organic matter and may not be available to plants before mineralization of the organic fractions. Cu in composts is less water soluble than Zn, but water solubility of Cu varied greatly among different composts (HE et al., 2001). Mean Mn concentration ranges from 400 to 600 mg kg^{-1} for composts from various countries, which is comparable to the average total Mn in soils (450 mg kg^{-1}) (BERROW & REAVES, 1984). Mn in composts may be more bioavailable than soil Mn. Water solubility of Mn in composts is much higher than Fe, with 7 to 47% of the total Mn being extractable. Mineralization increased Mn availability, especially in the MSW composts (HE et al., 2001). Composts generally contain more Zn than Cu, with a concentration range from 211 to 1650 mg kg^{-1}, which is 5 to 40 times greater than the mean total Zn in the world soil (40 mg kg^{-1}) (BERROW & REAVES, 1984). Zn in composts is highly water soluble and readily available to plants (SULLIVAN & MILLER, 2001).

2.9. Effect of compost and vermicompost on soil properties

2.9.1. Soil chemical properties

Application of compost can result in agronomic benefits in the soil chemical characteristics. An increase in total C in the form of OM leads to an increase in CEC, thereby increasing the number of exchange sites for mineral nutrients available for plant uptake (PANDEY & SHUKLA, 2006). A compost application of 34 to 67 Mg ha^{-1} can increase CEC in most mineral soils by 10%, thereby reducing leaching of fertilizer nutrients (McCONNELL et al., 1994). Compost OM can act as a liming agent in agricultural soils. Neutral to slightly alkaline composts can increase the pH in most acid soils, reducing the potential for Al and Mn toxicity (McCONNELL et al., 1994). Increases in pH are directly proportional to the proton and Al consumption capacity of the OM, specifically of humic and fulvic substances containing high carboxyl, phenolic, and enolic functional groups. As organic anions are adsorbed, a corresponding release of hydroxyls raises the pH of the soil. WONG et al. (1998) reported a linear relation between proton consumption capacity and total base cations in a tropical acid soil amended with plant residue compost, urban waste compost, farmyard manure, or peat. Similarly, BULLUCK et al. (2002) noted a two-fold increase in soil Ca concentration over 2 years following compost applications of 9 and 20 Mg ha^{-1} to two Typic Hapludult loams. In specific conditions compost has been found to affect soil pH even when applied at quantities as low as 22.4 to 44.8 Mg ha^{-1} (ALEXANDER, 2001). The incorporation of compost also has the ability to buffer or stabilize soil pH. The application of biowaste and vegetable waste composts increases soil organic matter and total N content (NEVENS & REHEUL, 2003; HARTL & ERHART, 2005). Increase in the quantity and quality (humic acids) of soil organic matter were shown in both sandy (WEBER et al., 2007) and clay soils (MELERO et al., 2007). Biowaste and vegetable compost application can increase plant available P, K (HARTL et al., 2003; MARTINEZ et al., 2003) and Mg (PARKINSON et al., 1999; WEBER et al., 2007) levels of soils, and soil CEC (BARTL et al., 2002; WEBER et al., 2007). Increased levels of soil EC due to the application of mixed green and animal waste compost was reported by MADEJON et al. (2001). Biosolids/sawdust compost applied to an eutric sandy Cambisol at 7.5, 15, 22.5, and 30 g kg^{-1} had little effect on organic P and on labile forms of P in a study by COUTINHO et al. (1997).

Compost application can ameliorate soil acidity (WONG et al., 1998; VAN De BERGHE & HUE, 1999). SPEIR et al. (2004) reported that in samples from the field trial, soil total C, N, P and Olsen P were increased markedly with increasing the compost application rate. Cation exchange capacity, exchangeable cation as will as total extractable and EDTA – extractable metals (Cu, Fe, and Zn) were also elevated. However, the total Cu reached to the allowable limit in biosolids compost amended soil. Additionally, N availability can be limited if compost C:N is too high. If the C:N ratio is greater than 30, soil N is usually initially immobilized and not available for plant uptake (NATHAN, 2004). In the composts with low carbon to nitrogen (C:N) ratios, approximately 8 % of compost N was available in the first year, whereas the compost with the high C:N actually immobilized soil N and reduced corn stands. Clearly, N availability is highly variable and largely dependent on the compost feedstock and maturity, soil chemical characteristics, and environmental changes in moisture and temperature, posing challenges to nutrient management in systems that utilize compost (NATHAN, 2004; MARIA, 2008). SULLIVAN et al. (2002) applied two composts (food waste + yard trimmings + paper and food waste + wood waste + sawdust) at 78 Mg ha^{-1} containing 870 to 1000 kg total N ha^{-1} to plots before seeding with tall fescue (*Festuca arundinacea*). They found that the compost did not significantly affect grass yield or N uptake in first year, yield increased 3% each in the second and third years. They concluded that compost N availability was limited by decomposition of compost OM in the soil and noted that a C:N ratio greater than 15 may have led to temporary net immobilization.

In general, the N availability to plants is low since the majority of the total compost N is bound to the organic N pool (AMLINGER et al., 2003; GUTSER et al., 2005; HARTL & ERHART, 2005).The mineral nitrogen content of composts is generally low, since N is partly lost during composting due to volatilization (ZWART, 2003). The organic portion of compost total N which is not readily available to plants, can be mineralized, and then potentially taken up by the plants, immobilized, denitrified, volatilized, fixed within the clay minerals and/or leached. Figure 2.8 illustrates the main transformations of compost N applied to the soil. N dynamics in compost amended soils may be influenced by various factors related to compost parameters, climatic conditions, crop types, soil properties and soil management practices (AMLINGER et al., 2003). Nevertheless, the presence of compost OM can help to mitigate mobility of certain metals in the soil solution, due to increased surface area and concomitant increase in adsorption sites. ZHOU and WONG (2001) examined the effects of dissolved OM from sludge compost on Cu sorption on two soils, an acidic sandy loam and a calcareous clay loam. An increase in OM in both soils significantly reduced Cu sorption by both soils. While sorption increased with increasing pH in unamended soils, the researchers observed a reduction in sorption at pH > 6.8 in compost-amended soils. They attributed this decrease to leaching losses associated with soluble OM and Cu complexes. MADRID et al. (2007) found that, soil heavy metal content increased compared to the control treatment and their results indicated that nutrients applied by compost were more available than native metals in soil.

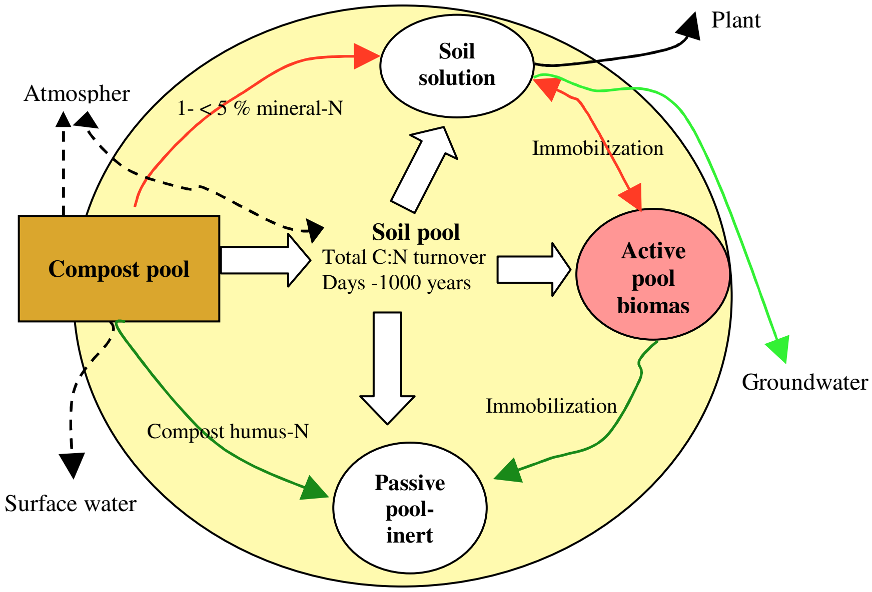

Fig. 2.8: The still sparely known fate of compost N in the soil organic matter pools (after AMLINGER et al., 2003)

2.9.2. Soil physical properties

Compost application to agricultural soil is shown to improve soil physical properties. This improvement is mainly a result of the organic matter addition to the soil by the compost application (MARIA, 2008; RASOOL et al., 2008). NATHAN (2004) reported that, the use of compost and vermicompost as soil amendments can have many positive effects on soil physical characteristics following high rates of application. TSADIALS et al. (2005) found that after three years of compost application, water retention capacity, available water, and infiltration rate were significantly increased, whereas bulk density and aggregate instability index were decreased. The physical properties of the amended soils were improved in all cases as far as the saturated and unsaturated hydraulic conductivity, water retention capacity, bulk density, total porosity, pore size distribution, soil resistance to penetration, aggregation and aggregate stability were concerned (AGGELIDES & LONDRA, 2000). With respect to total porosity, WANAS and OMRAN (2006) declared increasing the values of it as a result of applied compost. WANAS (2002) reported that compost treatments increased micro pores of sandy soil which resulted in an increase in soil available water and decreased in large pore space. TEJADA et al. (2006) stressed on the decrease of soil bulk density with compost addition.

High levels of organic humic matter soil amendment in the form of compost improve soil structure by increasing porosity and reducing the bulk density of an amended soil. Polysaccharides and other polymeric substances present in OM act as aggregating compounds and increase micropores in the soil (MASCIANDARO et al., 2000). The resulting increase in humic aggregates can increase the water-holding capacity of a mineral soil by 5 to 10 % by increasing the number of small pores (McCONNELL et al., 1994). RIZZI et al. (2004) concluded that compost can help the formation of large number of water stable aggregates, through links between small particles, strong enough to stand the dispersing action of water. SHANJIDA and SARWAR (2002) found that compost improved soil aggregation and increasing of water holding capacity. With respect to total porosity, macro and micro soil morphology were improved, especially the soil structure. Compared with the control treatment, the treated soil with compost had better aggregation in the surface layer due to change in fabric of ground mass and the altering changing of related distribution from enaulic to chitonic and partly gefuric. The dominant voids (large vughs and chambers) were modified to simple packing voids. Organic materials can be seen as coatings on pore walls (WANAS, 2002; WAHBA, 2007). In the field LYNCH et al. (2005) applied compost derived from crop residue alone and with other materials. They found that the improvement in soil physical properties (soil bulk density and water content) was obtained for compost treatments alone.

Many field studies have demonstrated decreases in soil bulk density and increases in porosity resulting from compost application. BULLUCK et al. (2002) noted an increase in OM and decrease bulk density in soils amended with “alternative” amendments, such as cotton gin trash, hay manure compost, or yard waste, compared to those using commercial synthetic fertilizers. AGGELIDES and LONDRA (2000) amended a clay soil (Humic Fluvaquent) and a loamy soil (Typic Xerochrept) in Greece with 0, 75, 150, and 300 m^3 ha^{-1} of a MSW, sludge, or sawdust compost. Compost application reduced bulk density of the loamy soil by up to 20 % in the 300 m^3 ha^{-1} treatment. Total porosity was improved up to 33 % compared to no compost application. Increased rates of compost application resulted in increased hydraulic conductivity: 33 to 95 % in the loamy soil, 55 to 168 % in the clay soil. Increases in water retention capacity and aggregate stability followed a similar pattern. Vermicompost with a high concentration of small aggregates may actually increase the bulk density, water holding capacity and total porosity of an amended potting substrate (MARIA, 2008; ATIYEH et al., 2001). PANDEY and SHUKLA (2006) showed that compost addition to sandy soil resulted in higher retention of rainfall, if application levels are sufficiently high. Increased soil porosity, field water capacity and the amount of plant available water, but only in the short time after compost application were demonstrated by WEBER et al. (2007). JOHNSON et al. (2006) showed that surface application of dairy manure compost increases water retention capacity and decreases soil bulk density. These results are in accordance with findings by AGGELIDES and LONDRA (2000) who used a composted mixture of MSW, sewage sludge and sawdust.

2.10. Effect of compost and vermicompost on plant properties

Several studies have evaluated the effect of vermicompost-amended potting media on plant growth greenhouse production. Generally, potting medium with 10 to 20 % vermicompost by volume provides adequate fertilization for transplant growth (SUBLER et al., 1998; ATIYEH et al., 2000a; ATIYEH et al., 2000b). In one study, germination rates of greenhouse tomatoes increased up to 15 % when vermicomposted was mixed with potting medium at 20, 30, and 40 % by volume. The highest marketable yield of fruit was reported in the 20 % mixture. Treatments consisting of 100 % vermicompost led to smaller growth and fewer leaves than other treatments, due to high-moisture and possible phytotoxicity (ATIYEH et al., 2000a). In plant tissue analyses, however, only 38 % of manure-N was recovered in spinach (*Spinacia oleracea*) plants, compared to 68 % uptake of fertilizer-N. KARMEGAM et al. (1999) evaluated germination efficiency, shoot length, roots length, nodulation, weight, and yield of green gram (*Phaseolus aureus*) grown in a 3:1 mixture of potting soil and vermicompost. Germination in vermicompost was 93 % versus 84% germination in a control (3:1 mix of potting soil and biodigested manure slurry). Additionally, green gram biomass increased 46 %, and shoot height by 28 %. Seed pod numbers increased by 35%, pod length increased by 13 %, seeds per pod by 20 %, and seed yield per plant by 52 %. Also, ARANCON et al. (2004) demonstrated that, vermicompost produced from food waste increased growth and yields of greenhouse peppers. Root nodulation in vermicomposted treatments increased 78 % above controls, suggesting increased microbial activity in the rhizosphere. HAMEEDA et al. (2007) mentioned that, compost and vermicompost have considerable potential for improving plant growth significantly when used as amendment to soil. OZORES-HAMPTON and VAVRINA (2002) grew organic tomato transplants in Florida using five different mixtures of worm castings, peat, and vermiculite (0:70:30, 18:52:30, 35:35:30, 52:18:30, and 70:0:30). During summer and fall, tomato growth increased linearly with vermicompost content, from 0.08 to 0.22 g DM $plant^{-1}$ whereas shoot biomass of fertilized controls was 0.11 g DM $plant^{-1}$. IGLESIAS-JIMENEZ and ALVAREZ (1993) showed that biowaste compost application at rates up to 50 Mg ha^{-1} increased ryegrass yield under greenhouse conditions, although not at the same levels as with mineral fertilization. MONTEMURRO et al. (2005) demonstrated that the application of relatively lower levels of compost to sunflower production in Italy resulted in similar oil and protein yield performance as mineral fertilization. Amendment with 10 or 50 % vermicompost increased dry matter yields of red clover (*Trifolium pretense* L.) and cucumber (*Cucumis sativus* L.) compared to soil alone. Vermicompost amendment also increased shoot P, Ca, and Mg concentrations, but may have reduced the activity of arbuscular mycorrhizal fungi in the soil (SAINZ et al., 1998).

In a field experiment, applications of a manure-sawdust co-compost increased tissue nutrient concentrations of P, K, Ca, Mg, and Zn in pak choi (*Brassica chinensis L.*) and corn compared to an unamended soil (WONG et al., 1999). The recommended rates of amendment were 25 Mg ha^{-1} for pak choi and 50 Mg ha^{-1} for corn. ATIYEH et al. (2000c) have reported the differences in the effect of vermicompost and composts on marigold and tomato plants. Plants were less responsive to the composts than vermicomposts. This difference in growth may be due to the fundamental differences between the composting and vermicomposting processes which use quite different microbial communities, with composting tending to result in the release of mineral nitrogen in the ammonium form, where as vermicomposting releases most of the nitrogen in the nitrate form (EDWARDS & BURROWS, 1988), the form readily available for plant uptake. Various green house and field studies have examined the effects of a variety of vermicomposts on a wide range of crops including cereals and legumes (CHAN & GRIFFITHS, 1988), vegetables (ATIYEH et al., 2000a); ornamental and flowering plants (ATIYEH et al., 2002) and field crops (MBA, 1996). Most of these investigations have confirmed that vermicompost usually have significant beneficial effects on plant growth (ARANCON et al., 2004; ASCIUTTO et al., 2006).

2.11. Carbon dioxide producing by burning wood

Biomass burning may significantly change the chemical climatology of our atmosphere. However, biomass may also be burned to clear forests for agriculture and grazing, control grass, weeds, and litter, eliminate agricultural waste, and server as domestic fuels (e.g. wood) (LEVINE et al., 1995, 1999). Burning wood emits more carbon dioxide per unit energy than combustion of any other fuel (WILLIAM, 2006). Conventional wood-fired power plants typically produce some of the same emissions as coal-fired power plants including carbon dioxide (CO_2) and carbon monoxide (CO). Use of local and shifting energy resources has been increasing in recent years. The most promising shifting energy resource is assorted biological energy (INGA & ZENONASE, 2008). CO_2 gas concentrates in the atmosphere causing the phenomenon of global warming. The carbon dioxide released when burning wood is about 1700-1900 g CO_2 for each 1000g of wood burnt (RADKE et al., 1991). In context, there are many countries using wood to produce electricity and/or heat is technically proven. Wood can be burned and the heat used to provide hot water or to raise steam for direct industrial use or for electricity generation. Alternatively, wood can be subjected to modern gasification or pyrolysis techniques: the resulting gases or liquids can be burned in an engine or turbine to generate electricity, or in a boiler to produce heat. On the contrary, the major disadvantages of the previous techniques its produced large quantities of carbon dioxide. Domestic CO_2 mostly coming from burning of biodegradable solid wastes in open dumpsites adds 414 M tons per year (ABRIGO, 2008). CO_2 emission is probably the top concern of environmentalists when it comes to greenhouse gas issues since this emission was estimated to contribute about 55 % of the heat waves (radiative forces) relevant to global warming (IPCC, 1990). The reduction of greenhouse gas emissions must be the ultimate goal to control global warming coupled with the enhancement of carbon fixers or users.

Aerobic composting is probably a pioneering approach to help reduce the emissions of CO_2, methane and nitrogen oxides (ABRIGO, 2008). The derived mathematical equations between agricultural solid wastes and CO_2 emissions suggested by Abrigo are: $Y = 1.275X$ and $Y = 0.665X$ for burning and composting respectively. For municipal solid wastes the corresponding equations are: $Y = 0.345X$ and $Y = 0.18X$, Where: Y = tons carbon dioxide emission, and, X = tons biodegradable solid wastes. The corresponding equations on dry basis are: $Y = 1.720X$ and, Y = 0.898X. These derived equations can be used to estimate the CO_2 emissions from different regions that generate biodegradable solid wastes either on wet or dry basis. The CO_2 reduction equations through aerobic composting of agricultural and municipal biodegradable solid wastes are: Y = 0.61X and Y = 0.165X respectively. On dry basis, the equation is: Y = 0.825X for both sources of wastes (ABRIGO, 2008). This means that for every ton of biomass waste (dry weight) composted instead of being burned, 0.825 ton CO_2 is not generated. Addition of compost to the farm lands will minimize nitrogen oxide emission equivalent to approximately 5 % of total anthropogenic CO_2 released to the air as well as enhancing the carbon absorption by the soil roughly equivalent to another 5 % of the total CO_2 emission. These are the relevant mitigating effects of aerobic composting on the global warming phenomenon. Actual experimental studies on aerobic composting of agricultural and municipal solid wastes reveal that anthropogenic CO_2 emission can be reduced by 13%, methane emission by 11 % and nitrogen oxide emission by 14 %.

Moreover, addition of compost to the farm lands will minimize nitrogen oxide emission equivalent to approximately 5 % of total anthropogenic CO_2 released to the air as well as enhancing the carbon absorption by the soil roughly equivalent to another 5 % of the total CO_2 emission. These are the relevant mitigating effects of aerobic composting on the global warming phenomenon (PIMENTEL et al., 2005). If these biodegradable solid wastes are composted under controlled conditions with sufficient aeration, calculations based on carbon analysis of raw materials and finished compost from actual experiments, the CO_2 emission from the agricultural solid wastes is only 5.51 B tons and only 216 M tons from the municipal solid wastes or a total decrease of 5.248 B tons. Relating this decrease to the total manmade carbon dioxide emission of 40 B tons, this translates to approximately 13 % of the total emission. From the previous discussion, using composting wood instead of burning wood helps to reduce CO_2 and other potentially damaging emissions (ABRIGO, 2008).

2.12. Improvement and revegetation of coal mine waste

2.12.1. Introduction

In Germany lignite can be found in six deposits (Fig. 2.9). The three most important ones are the Rhenish, the Lusatian and the Central German lignite mining districts. In each of these regions lignite is obtained by strip-mining. However, different strip-mining technologies are used due to differences in the geological setting of the respective districts (HUETTL, 1998). ***Lignite*** is one of the first products of coalification and is intermediate between peat and bituminous coal. Its colour is brown to black and it has been formed from peat and under moderate pressure, dry lignite contains about 60–75 % carbon. The mining region of Lusatia district comprises the area of southern Brandenburg and northeastern Saxony, 130 km southeast of Berlin and 100 km north of Dresden (Fig. 2.9). It is situated at the southeastern edge of the North German lowland area, which has been formed by the Saale and Weichsel glacial epoch, respectively. Most glacial deposits are made up of sandy soils, except in the north western part of the region. Mine sites were opened both in glacial valleys and ground moraine areas which results in different hydrological situations. Predominant land use in the non-mining areas is forestry which covers ca. 70 % of the total area. Agriculture is traditionally of minor importance in most parts of Lusatia as the soils are generally poor in nutrient and infertile (WIEGLEB, 2001). Open-cast lignite (brown coal) mining operations in the Lusatian District have created an area of almost 1000 km^2 covered by spoil heaps of clastic overburden sediments of tertiary and quaternary age (HUETTL & WEBER, 2001). Brown coal mining pits are anthropogenically disturbed geological systems (Fig. 2.10). The digging of the these open pits often required an extensive lowering of the water table by several tens of meters and removal of large quantity of overburden material, which consist mostly of quaternary and tertiary sediments with sulphide-bearing minerals such as pyrite and marcasite (KOHFAHL, 2004). Tertiary and quaternary substrates can be identified: lignite- and pyrite-containing substrates stemming from tertiary sediments and lignite- and pyrite-free substrates from quaternary sediments. The majority of these substrates are pure sands and loamy sands. Figure 2.10 showed the various stages that occur in soil during the mining operations. The lignite mining is directly connected with land claiming and thus represents a considerable intervention of nature (Fig.2.10.a). In order to compensate the insufficient conditions of direct dumping with overburden conveyor bridges during the winning of suitable soil substrates, the bridge dumps of future open-cast mines are basically covered with spreader spoiling material from the advance cuts (Fig. 2.10.b). This ensures a selective winning and spoiling of cultivable soil material (Fig. 2.10.c). The soil is an important factor for planning and creating of the post-mining landscapes. The physical and chemical properties of the raw dump soil have decisive influences on the possible future land use of the areas (HAEGE, 1996).

Fig. 2.9: Location of lignite mining regions in the Federal Republic of Germany

1 Rhenish lignite mining region
2a Lower Lusatian lignite mining region
2b Upper Lusatian lignite mining region
3 Central German lignite mining region
4 Helmstedt lignite mining region
5 Hessian lignite mining region
6 Bavarian lignite mining region

2.12.2. Physical properties of the studied soils

The physical properties of the dumps are problematic. Dumping creates loosely packed substrates. Therefore extended landslides can occur when the groundwater level rises. Common characteristics are a mainly sandy texture (About 80 % of the natural soils in Lower Lusatia are sandy and flat). The climate in the Lusatian region can be described as temperate. The mean air temperature per year was 9.4° C and the rainfall was 576 mm. the negative physical properties are reduced soil wettability, insufficient soil biological activity and disturbed air-water balances (HAEGE, 1996; KATZUR & HAUBOLD-ROSAR, 1996). The wetting resistance of this substratum is consequences increased surface run-off leading to considerable damages by water erosion. As a reason for this phenomenon colloidally distributed wax residues of tertiary reed grasses and other alcohol soluble substances are presumed. As wetting resistance is only relevant in the summer term after intense drying of mine soils, it is probably also caused by hydrophobic reaction of iron- and aluminium-humates. Wetting resistance increases susceptibility of mine soils rich in fine sand to wind erosion. That is why sandstorms are almost daily events on vegetation-free dumps (KATZUR & HAUBOLD-ROSAR, 1996).

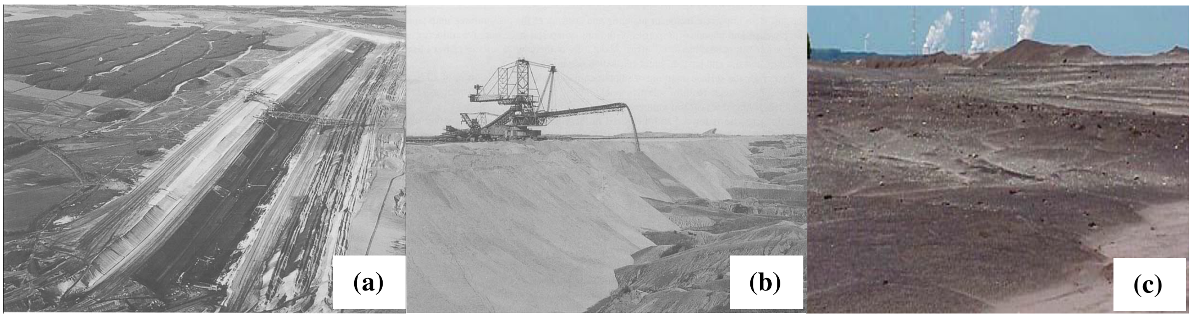

Fig. 2.10: Open-cast mine in Lusatia, with overburden Conveyor Bridge (adapted from HAEGE, 1996)

(a) Open-cast mine in Lusatia, with overburden conveyor bridge.
(b) Non-arable overburden Conveyor Bridge dumps are covered by arable substrates from the selective advance cut operations.
(c) The residual soil after completing of drilling and digging operations.

The excavation of lignite causes a mass-deficit. In Lusatia there are many pits have been formed for collecting coal. These pits turn into post-mining lakes once the original groundwater level is reestablished (HUETTL, 1998). Thereby, strip-mining increases the amount of surface water in the post-mining landscape. As a consequence residual pits create an additional demand for water which is estimated to be 4.0 billion m^3. This situation presents a further burden for the compensation of the disturbed water balance. Lignitic mine soils of the Lusatian District consist of a relatively large (thickness 50–100 cm, length several 10s of meters) and regular structure of inclined spoil layers. In those layers lignitic and other components of various sediments are randomly embedded at a smaller or local scale (GERKE et al., 1998; BUCZKO et al., 2001). Soil heterogeneity at two different scales was observed in those lignitic mine soils regarding potential water repellency (GERKE et al., 2001; HANGEN & GERKE 2005).

2.12.3. Chemical properties of the studied soils

In Lusatian mine soils spoil heap sediments often abound in lignitic components in form of fragments or as coal dust (NEUMANN, 1999). Due to the sulphide mineral content in the original overburden sediments of up to 1.7 wt %, oxidative weathering within the largely unsaturated spoil heaps may lead to acid mine drainage, which poses a potential threat to groundwater quality (EVANGELOU, 1995). The corresponding acidification of the spoil heap sediments can impede the success of mine soil reclamation and revegetation practices (HANGEN & GERKE 2005). The pyrite content in these substrates exposed to the atmosphere leads to a high potential for acid production and consequently very phytotoxic site conditions. At these sites, phytotoxic acid conditions are prevailing due to the deposition of pyrite-containing sediments originating from Miocene. These sediments are extremely acid (2.5 – 3.0) and can contain up to 50.0 g kg^{-1} carbon derived from lignite (HUETTL & WEBER**,** 2001). Therefore, it is often difficult to initiate plant growth in the post mining landscape. It is even more difficult to achieve successful recultivation in the sense of establishing new agricultural and forest ecosystems that can be used by man as it was the case before mining. Due to the mining technology using over burden-conveyer bridges (HAEGE**,** 1996) about 60 % of the land surface today consist of at least partially lignite- and pyrite-containing substrates and are characterized by low nutrient content (KATZUR, 1998). Low content of recent organic matter, low pH and a low nutrient status are the main chemical problems of the mining substrate. Deficiency of N, a lesser extent of P, and K in mine spoils represents a general problem (BARNHISEL et al., 1982; STRZYSZCZ, 1996). During the early stage of mine soil development the element budgets of these sites are controlled by pyrite oxidation releasing large amounts of iron and sulfuric acid, inducing enhanced weathering of primary minerals and precipitation of secondary minerals (GAST et al., 2001). The tertiary substrata contain several amount of geogenic organic matter (GOM) which it was decomposed by the microbial activity in mine soils even at the very early stages of soil development (RUMPEL & KOGEL-KNABNER, 2002). Restoring N cycling is one of the major goals of ecosystem recovery in environments disturbed by mining (HUETTL & WEBER, 2001). In another study CHABBI et al. (2008)

demonstrated that, the mine sites (tertiary sediments) contain high amounts of geogenic organic carbon and nitrogen in the form of lignitic fragments, which may serve as nutrient sources for plant regrowth. Lignite was also shown to contain high amounts of exchangeable NH_4 (HONS & HOSSNER, 1980), and the lignite and pyrite containing substrates may release NH_4 into soil solution (BLECHSCHMIDT et al., 1999). Much of the nitrogen is leached as NH_4 beneath the rooting zone from these sites (GAST et al., 2001). At young mine sites (<40 years), this output was found to be disconnected from input by litter fall or atmospheric deposition and could only be explained by nitrogen release from GOM (SCHAAF, 2001). In the main rooting zone of these mine soils, N fluxes were found to be low, probably as a result of plant uptake (GAST et al., 2001). However, it is not clear to what extent plants are using the nitrogen released from lignitic fragments. Carbon and nitrogen in rehabilitated lignite containing mine soils can be derived from plant material as well as from lignite inherent to the parent substrate (CHABBI et al., 2008).

Coal contains various inorganic minerals in addition to the major organic components. Inorganic matter exists in two forms. One is the inherent mineral matter within the coal particles, and the other is adventitious inorganic material remaining external to the coal particles (CHEN et al., 1999). Minerals in coal vary widely. The approximate order of the amounts present is: *the shale group species* (comprised of muscovite, illite and montmorillonite) which are principally Na, K, Ca, Al, Mg and Fe silicates; the *kaolin group* (kaolinite-aluminum silicate); the *sulphide group* (pyrite and marcasite); the *carbonate group* (calcite and ankerite) and probably of the lowest occurrence, the salt group, including gypsum, sylvite and halite (OEZBAYOGLU, 2006). BLOETHE et al. (2008) reported that, coal mining are characterized by low pH and high concentrations of Fe (II) and sulfate. Humic acids extracted from lignite have some characteristics that are comparable to humic acids in soil organic matter and peats including the presence of polyphenolic cores, phenolic, hydroxyl and carboxyl groups with pH dependent dissociation (WHITELEY, 1993). SPACCONI et al. (2002) found that humic acids isolated from lignite have higher hydrophobicity than humic acids from compost. C:N ratio for lignite humic acid (LHAs) is significantly higher than those observed for the soil humic acid and indicates a relatively high stage of coalification (RUMPEL & KOGEL-KNABNER, 2002). The differences between the composition of LHAs and oxidized bituminous coal are mainly in much higher values of O, H, dissociation constants and some metal binding capacities and lower values of C and aromaticity index in LHAs and/or oxidized lignite samples (KURKOVA et al., 2004).

2.12.4. Vegetation properties of the studied soils

Vegetation types occurring in the East German post-mining landscapes are relatively well-described (see PIETSCH, 1998; FELINKS et al., 1999a, b; FELINKS & WIEGLEB, 2001). These vegetation types cannot be regarded as homogeneous and well-circumscribed entities. They show an extremely differentiated composition. This is due to the small scale heterogeneity and the ongoing dynamics of the respective sites. A direct time dependence of post-mining vegetation development has not yet been demonstrated. Only general, partly trivial, trends were emphasized, such as the change in dominant growth forms. The scope of recultivation activities was very wide in Lusatia soils. Besides red oak, also pine and robinia as well as poplar in combination with common alder and larch in combination with lime as well as sessile oak were planted successfully (HAEGE, 1996). More frequently, pine was preferred and extensive pine forests were established which produced good growth, but from the ecological viewpoint were not stable and satisfactory for regional and cultural reasons. According to the local circumstances of Lusatian region, various types of initial vegetation are possible. Initial vegetation is subsequently followed by a large number of stages and types which form a complex network. Some of these stages are stabilized by a dense vegetation layer or competitive power of the dominant species. The direction of succession is influenced to varying portions by neighborhood effects, facilitation, disturbance, and other mechanisms. The duration of the stages and the transition probabilities cannot be exactly predicted in the present state of knowledge. Besides its scientific importance, primary succession is regarded as an adequate means of restoration leading to areas likewise interesting for nature conservation and considerate tourism (HUETTL & WEBER, 2001).

2.12.5. Summary of soil Problems

The physical and chemical properties of the raw dump soil have decisive influences on the possible future land use of the areas. Sulphuric acid is formed and mobilized in these raw soils during the weathering of the sulphide minerals markasit and pyrite. This causes an extreme ecological site conditions characterized by very low pH values, low nutrients content, low content of recent organic matter and enhanced solubility of heavy metals and aluminium. Other negative properties are subversive soil structure, reduced soil wettability, insufficient soil biological activity and disturbed air-water balances (HAEGE, 1996). Moreover, About 80.0 % of the natural soils in Lower Lusatia are sandy and flat. Stabilization of added organic materials in quaternary substrates may be limited due to low clay and fine silt contents of the sediments and a supposedly low protection capacity for OM. At some of these recultivated sites, proportions of clay and silt in the sediments together account only for 4.0 % of the total mineral matter (KATZUR & HAUBOLD-ROSAR, 1996). In contrast, the soils in tertiary substrates have high soil organic matter stabilization, in due to high amounts of geogenic organic carbon and nitrogen in the form of lignitic fragments (GAST et al., 2001). It became obvious that the success of revegetation was related to the geochemical properties of the dump substrates.

2.12.6. Successful amelioration in the studied soils

The objective of amelioration is to achieve a sustained improvement of pH in sulfurous mine soils and to affect nutrient supply in a way that the following recultivation may be carried successfully. Recultivation contributes to further improvement of soil properties and to the restoration of soil functions. Lime, calcium oxide, compost and sewage sludge are the most soil conditioners used in improvement coal mine waste. Amelioration of sulfurous and carboniferous mine in Lusatia soils is always combined with mineral fertilization (WILDEN et al., 1999). In another study, for successful reclamation, high application amounts of basic materials like limestone or alkaline fly ash are required to neutralize soil acidity and hence create the potential for plant growth (CHABBI, 2004). Due to the lack of nutrients in these spoil substrates mineral fertilizers are conventionally applied as a fundamental reclamation measure. Because of the sandy texture of these spoil substrates the risk of nutrient losses from the mineral fertilizers via seepage water leaching is relatively high (WILDEN, 2000). An alternative treatment to the amendment of mineral fertilizers might be the application of organic residues like compost or sewage sludge (WILDEN et al., 2001). A field study was conducted for comparing the effects of three different fertilizer treatments (mineral fertilizer, sewage sludge and compost) on soil solution chemistry of both lignite and pyrite containing spoil as well as a lignite and pyrite free spoil. At both sites application of mineral fertilizer led to an immediate but short term (about 1 month) increase of NO_3, NH_4 and K concentrations in soil solution down to a depth of 130 cm. Application of sewage sludge caused a long term (about 16 months) increase of NO_3 in the topsoil, whereas NO_3 concentrations in the subsoil were significantly lower compared to the mineral fertilizer plot. Compost application resulted in a strong long-term increase of K in soil solution, whereas NO_3 concentrations did not increase. Concentrations of PO_4 in soil solution depend on solution pH and were not correlated with any treatment (WILDEN et al., 1999). Compost organic matter can act as a liming agent in agricultural soils. Neutral to slightly alkaline composts can increase the pH in most acid soils, reducing the potential for Al, Fe, and Mn toxicity (MCCONNELL et al., 1994). Increases in pH are directly proportional to the proton and Al consumption capacity of the OM, specifically of humic and fulvic substances containing high carboxyl, phenolic, and enolic functional groups. As organic anions are adsorbed, a corresponding release of hydroxyls raises the pH of the soil (WONG et al., 1998).

3. MATERIALS AND METHODS

3.1. Compost experiments

3.1.1. Collection and preparing compost raw materials

Feedstock preparation is an important first step to ensure that the composting process is optimized. Moisture content, carbon, nitrogen, and micronutrients are the raw materials that will determine the formulation of the mix. In general, a feedstock of organic materials high in carbon, such as wood, ground branches, and twigs, should be mixed with nitrogen-rich materials, such as LM and HM. The following raw materials were used:

Two types of wood namely pines *(Pinus sylvestris, PS*) and oak (*Quercus rubra, QR*) were used together in the first compost experiments, while only *QR* wood was used in the second compost trial. Bark decompose is more slowly than wood due to wood bark tends to be hydrophobic, contains toxic levels of volatile monoterpenes ($C_{10}H_{16}$), high amount of lignin, wax, tannins, and resins. These substances were protected wood bark that resists decomposition (HOITINK, 1980). Wherefore, the outer corky bark layer was removed from these woods. The wood free from bark was chopped, shredded, and crushed to transfer it into cheeps at size of 2 cm of length and 0.2 cm thick. The woodchips were soaked in tap water for 24 hr (ROU, 2000a), after that left on plastic mattress to dispose of excess water before mixing with LM (Fig. 3.1).

Fig. 3.1: Preparation of wood

(a) Crushed wood (b) Woodchips at size 2 cm length and 0.2 cm thick (c) Soaking woodchips in water

The LM was taken from Rangsdorfer See, Brandenburg, using handling methods (Fig. 3.2), and left on plastic mattress for nearly 70 % moisture content before mixing with woodchips.

Fig. 3.2: Collection and preparing the lake mud

(a) Collect the LM (b) placing the LM on the plastic mattress (c) The *LM* at nearly 70 % moisture content

The mature HM was obtained from one of the farmers breeders for horses in the village of Golm, in Potsdam. The straw and plant residues were removed from the manure. The manure was crushed by hand to small pieces before mixing with wood.

The used compost water was obtained from PRU ARKADES Company (Neuendorf, Brandenburg). Compost water was filtered before using in order to remove the large suspended materials.

Adult tiger worm (*Eisenia fetida*, *EF*) and European nightcrawlers (*Dendrobaena veneta*, *DV*) had been bought from Tacke GmbH Borken and Martin Langhoff-Dueren respectively. Both types of worm were used in the first compost experiment, while only *EF* was used in the second compost trial.

Gravels sized 3 to 7 mm were placed in the bottom of the pots to improve aeration and drainage through compost materials. The gravels were obtained from one of the architectural firms (Fig. 3.3.a).

Equipments:

Pots 4 liter (21.8 cm depth, 18.7 cm diameter top, 12 cm diameter bottom) and 40 liter (47cm depth, 44 cm diameter top, and 31 cm diameter bottom) were used in first and second compost trials respectively (Fig. 3.3).

Nets: For the first compost trial a plastic net 0.50 mm diameter was used, like nets used to cover the windows. For the second compost trial a polypropylene wire mesh 0.56 mm diameter for aperture (30 mesh in 30 inch) obtained from Drahtweberei Graefenthal GMBH, Thueringen. Part of the net placed in the bottom of the pot and another part are fixed in the above as a cover to prevent worms from escaping (Fig. 3.3). The compost raw materials (wood, lake mud, horse manure) were analyzed for some physical and chemical properties as shown in Table 3.1. The chemical analysis of both tap and compost water was recorded in Table 3.2.

Fig. 3.3: preparation of the used pots

(a) Empty pot with net in the bottom (b) Gravels inside pot (c) Pot covered with the net after filled with the mixture

Table 3.1: Some physical and chemical properties of raw materials used for composting

Properties		***QR***	***PS***	**LM**	**HM**
Water holding capacity	[%]	335.00	400.00	92.00	300.00
Dry bulk density	[g cm^{-3}]	0.04	0.04	1.42	0.16
Electrical conductivity	[dS m^{-1}]	0.27	0.23	0.55	3.83
pH-value	[-]	6.21	6.30	6.94	7.47
Organic matter	[%]	98.47	98.22	24.94	62.29
Total organic carbon		47.73	46.63	14.46	32.25
Total extractable carbon		24.78	24.54	6.97	21.50
Fulvic acid		1.40	0.96	1.17	1.58
Humic acid		2.56	2.43	2.59	4.84
Total carbon		50.75	50.73	18.27	32.30
Total nitrogen		0.16	0.14	1.17	2.29
C:N ratio	[-]	317.18	362.35	15.66	14.10
Total Phosphorus	[mg kg^{-1}]	153.45	152.91	412.14	2823.17
Total Potassium		382.80	301.40	7310.90	10320.12
Total Calcium		320.10	315.20	17754.00	5260.30
Total Magnesium		89.30	73.70	1564.20	2033.30
Total Copper		3.64	4.82	13.32	15.80
Total Iron		279.37	281.40	7708.80	2732.45
Total Manganese		53.78	48.04	471.90	149.50
Total Zinc		4.69	6.94	64.19	76.60

Table 3.2: Some chemical properties of tap and compost water used for composting

Properties		Tap water	Compost water	Reference
EC	[dS m^{-1}]	1.15	12.33	(APHA, 1998)
pH-value	[-]	7.45	5.14	
P	[mg L^{-1}]	0.20	1407.21	(WATANABE; OLSEN, 1965)
K		235.00	2510.00	(APHA, 1998; HAVEZOV, 1996)
Ca		107.00	2490.00	
Mg		13.00	420.00	
Fe		0.01	10.88	
Mn		Traces	19.00	
Cu		0.08	0.44	
Zn		0.50	8.10	

3.1.2. Mixing raw materials, design and procedure

3.1.2.1. First compost experiment

A pot experiment of 4 L volume was carried out at 01.08.07 in a greenhouse near Potsdam. After processing and preparation of *PS* and *QR* woods, as mentioned above (paragraph 3.1.1.), each of the used woodchips was mixed separately with the prepared LM. The woodchips and LM were mixed at ratio (w/w) of 1:1 and 1:3 (wood: LM). These ratios were used based on C:N ratio of the mixture which were represent of 30:1 and 20:1 and chosen on the basis of our previous studies on composting (LAOS et al., 2002; NATHAN, 2004; MARIA, 2008). The used pots in this experiment were arranged in ***split split plot design*** with three replicates (Table 3.3 and Fig. A.1). Each mixed ratio (main plot) consists of 18 pots. The pots of each main plot were divided into two sub-plots (9 pot / sub-plot). The first sub-plot was irrigated by tap water until the experiment end (100 day), where the second sub-plot was irrigated by compost water for the first 30 day, where this water was used as a source of microorganisms and irrigated after that by tap water until the end of experiment. Net of 0.50 mm diameter was put on the bottom of the pots followed by 1 cm thick layer of gravels. The pots were filled after that by the used mixture at the depth of 17 cm and covered by the net. The pots were submitted to a process of aerobic composting with periodic turning at seven-day intervals to ensure availability of sufficient amount of oxygen to be utilized by microorganisms (HELLAL, 2007). The pots turning were done manually during the first 30 days (composting period) and stopped after adding worms (vermicomposting period).

Table 3.3: Experiment design of the first compost trial

Water type	**Mixing ratios** (Wood: LM) w/w	**Infection worms**	**Number of replicates**	
			QR wood	*PS wood*
Tap water during all compost period	1:1	0	3	3
		EF	3	3
		DV	3	3
	1:3	0	3	3
		EF	3	3
		DV	3	3
Compost water for 30 days after that tap water	1:1	0	3	3
		EF	3	3
		DV	3	3
	1:3	0	3	3
		EF	3	3
		DV	3	3

After passage one month of composting period (FREDERICHSON et al., 2007), this was done to avoid exposure of worms to the possible high temperatures during the initial thermophilic phase of composting, each of sub-plots was divided into three sub-sub-plots (3 pots/sub-sub-plot). The first sub-sub-plot was left without worm infection. The second sub-sub-plot was infected by *EF* worm at rate of 25 worms/kg mix (MABOETA & RENSBURG, 2003) and the third sub-sub-plot was infected by *DV* worm at the same infection rate. During composting period the moisture level of all pots was remained at 50-60 % by weight of each treatment and 70-80 % during vermicomposting period where the water was added to the pots when this moisture level decreased. Separately in each treatment the leachate water was used again for irrigation to restore the lost nutrients.

3.1.2.2. Second compost experiment

The successful wood vermicompost from the first compost trial (*QR*) was carried out in more large pot (40 L) in greenhouse at 01.08.08. The prepared WC, LM, and HM were mixed separately at 1WC : 2LM, 1WC : 2HM and 1WC : 1LM : 1HM mixed ratios (w/w). These ratios were used based on C:N ratio of the mixture which was represent in the range of 25 to 30. Propylene net of 0.56 mm diameter was added on the bottom of the pots followed by the layer of gravel at 3 cm thick. The pots were filled after that by the used mixture at the depth of 40 cm and covered by the net. Similarly, as stated above in the first compost trial the pots were submitted to a process of aerobic composting with periodic turning at seven-day intervals to maintain porosity. The used pots in this experiment were arranged in ***split plot design*** with six replicates as shown in Table 3.4 (Fig. A.5, A.6). The number pots of each mixed ratio (main plot) were consisting of 18 pots. The pots of each main plot were divided into three sub-plots. The first sub-plot (6 pots) was irrigated by compost water until the end of experiment (100 days) and uninfected by worm, where the second and third sub-plot (12 pots) was irrigated by compost water for the first 30 days, and irrigated after that by tap water until the end of experiment. The second sub-plot (6 pots) left without worms whereas the third sub-plot (6 pots) was infected by *EF* worm which was selected as the best worm from the first compost experiment at rate of 25 worms/kg mixture. During composting period the moisture level of all pots was controlled as previous in first compost trial, except the first sub-plot which maintained at 50-60 % moisture content during all composting period. As shown in the first compost trial, the leachate water was used again for irrigation.

Table 3.4: Experiment design of the second compost trial

Mixing ratios (w/w)	**Water type**	**Infection worm**	**Number of replicates**
1WC:2LM	Compost water all composting period	0	6
	Tap water after one month compost water	0 *EF*	6 6
1WC:2HM	Compost water all composting period	0	6
	Tap water after one month compost water	0 *EF*	6 6
1WC:1LM:1HM	Compost water all composting period	0	6
	Tap water after one month compost water	0 *EF*	6 6

3.1.3. Analytical methods

For both the first and second compost experiments during composting period and/or at the end of the experiment, compost samples of each plot was air-dried, crushed, sieved through a 2 mm sieve and analyzed for some physical and chemical properties as follow:

3.1.3.1. Physical analysis

The degrees of temperature [°C] in each of the pots were recorded daily through out the composting period using temperature probe (thermometer). A compost thermometer was inserted in the pot and the temperature was recorded when it reaches to equilibrium. The average temperature of replicates of each treatment was calculated.

Dry bulk density (*BD*, [gcm^{-3}]) of the compost was determined according to LEEGE and THOMPSON (1997) and BLAKE (1965). The calculated values were given by the following relationship (Eq. 3.1), where the *W* is the weight of the air dried sample (g) and *V* is the volume of the cubical sample (cm^3).

$$BD\ (g\,.cm^{-3}) = W/V \qquad \text{(Eq. 3.1)}$$

Water holding capacity (WHC, [%]) is dependent upon the organic matter content and particle size**.** Gravimetric water-holding capacity is the amount of water held in pores after gravitational loss for a specified time. This test is used to assess the utilization of compost for potting media. Water-holding capacity is a measure of the water retained by a compost sample after free drainage for 4 h according to LEEGE and THOMPSON (1997).

3.1.3.2. Chemical analysis

Carbon dioxide evolved by burning wood calculated from total carbon determined by in a flash combustion Thermo Finnigan, Flash 1112 Series elemental analyzer in standard mode. Ignition of 1-2 mg of fine powder wood was ignited in a tin cap in O_2 at 1000° C according to TABATABAI and BREMNER (1991). The oxide produced was analyzed using a thermal conductivity detector. Simply multiply carbon value by (44/12) to calculate how much carbon dioxide is represented by an amount of carbon using the following equation (Eq. 3.2), Where the *TC* is a total carbon (g), 44 and 12 is the molecular mass of CO_2 and C respectively.

$$CO_2\,(g \cdot kg^{-1}) = TC \times (44/12) \qquad \text{(Eq. 3.2)}$$

Microbial respiration rate (CO_2) was measured using a modified procedure described by ADAS (2005). Weakly approximately 100 g dry weight of compost sample at 60 % (w/w) moisture content was sealed in a 1.0 L vessel along with a beaker containing a known volume of 1 M NaOH solution. Air is pumped at a rate of 2 – 4 l/hour, initially through a 1 M sodium hydroxide solution to remove atmospheric carbon dioxide, then through the compost incubation vessel and finally through a diffuser at the base of a 150 ml test tube filled with 50 ml 1 M NaOH. Any carbon dioxide produced by the compost is flushed through and trapped by the 1 M NaOH as sodium carbonate. The samples were incubated for 7 days at room temperature (24 ± 2° C). During the incubation, the released CO_2 was captured by the NaOH solution (Fig. 3.4), which was then analyzed titrimetrically at regular intervals with 1M hydrochloric acid after the collected sodium carbonate is precipitated as barium carbonate after addition of 4 ml 1 M $BaCl_2$. The CO_2 evolved was calculated using the formulas (Eq. 3.3 and 3.4).Since there is a large variation in the evolution of CO_2 during incubation, the peak CO_2 evolution rate was used to represent compost stability. Determination of blank value, an apparatus and reagent blank test shall be carried out in parallel with the determination, by the same procedure using the same quantities of all reagents but omitting the test portion. According the following equations, the B_{vol} is the volume in ml M HCl for the blank titre, S_{vol} is the volume in ml M HCl for the sample titre, 44 and 12 is the molecular mass of CO_2 and C respectively, *w* is dry weight of the sample per gram (at 105° C), and d is the time per day.

$$CO_2(mg\,.kg^{-1}.\ day^{-1}) = (B_{vol} - S_{vol}) \times (44/12) \times (1000/w) \qquad \text{(Eq. 3.3)}$$

$$Total\ CO_2(mg\,.kg^{-1}.\ 7days^{-1}) = \sum(d_1 + d_2 + \ldots\ldots + d_7) \qquad \text{(Eq. 3.4)}$$

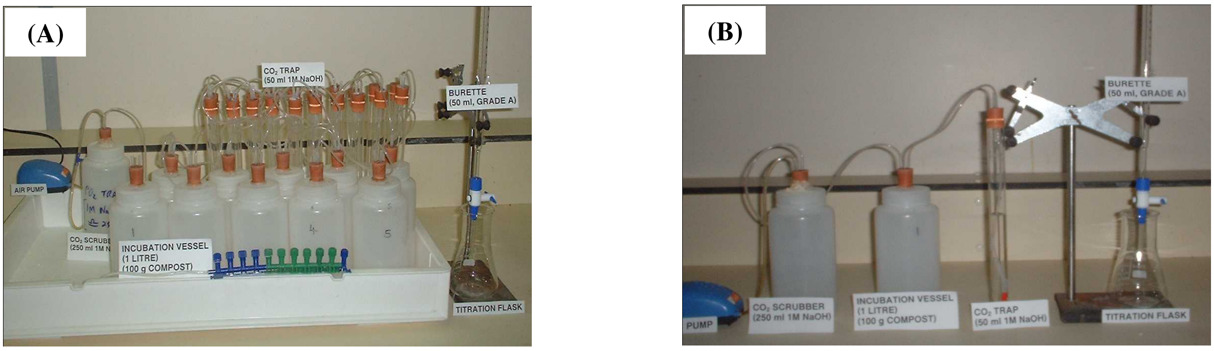

Fig. 3.4: Carbon dioxide test unit

(A) Complete unit (B) single unit

The degree of biodegradation (DB) was calculated according to the equations (Eq. 3.5, 3.6) used by ISO 14855 (1999). The theoretical amount of carbon dioxide ($ThCO_2$) was calculated from total organic carbon (C_{TOT}) measured according NELSON and SOMMERS (1982), which assuming that all the organic carbon of the test material is transformed into CO_2, $\sum(CO_2)_T$ is the cumulative amount of CO_2 evolved from the test material between the start of the test and time *T*, and $\sum (CO_2)_B$ is the cumulative amount of CO_2 evolved from the blank between the start of the test and time *T*.

$$ThCO_2(mg\,.kg^{-1}) = C_{TOT} \times (44/12) \qquad \text{(Eq. 3.5)}$$

$$DB\,(\%) = \frac{\left[\sum(CO_2)_T - \sum(CO_2)_B\right]}{ThCO_2} \times 100 \qquad \text{(Eq. 3.6)}$$

pH value was measured in compost $CaCl_2$ 0.01M suspension (1:10 w/v) after shaking and letting for 30 min by pH meter according to TAKESHI et al. (2004) and DIN ISO 10390 (2002).

EC [dS m^{-1}] was measured using electrical conductivity apparatus in the compost extraction solution at 1:20 compost: distilled water (w/v) ratio at a temperature of 25° C according to TAKESHI et al. (2004) and DIN ISO 11265 (1997).

Cation exchange capacity (CEC) as [cmol kg^{-1}] in due to high amount of $CaCO_3$ in compost it was determined by using the unbuffered methods (0.1M $Bacl_2$ methods) according to HENDERSHOT and DUQUETTE (1986). CEC was measured by estimated Ba expelled by $CaCl_2$ 0.1M in the collecting solution by atomic adsorption spectrophotometer using the following equation (Eq. 3.7), where the v is the volume of leachate solution (L), *Eq* is the Equivalent weight of barium and *w* is the sample weight (g).

$$CEC\ (cmol \cdot kg^{-1}) = \frac{[(mg \cdot L^{-1} Ba) \times v \times 100]}{(Eq \times w)} \qquad \text{(Eq. 3.7)}$$

Organic matter content [%] was determined was determined by weight loss on ignition at 550° C according to DIN 19684-3 (2000).

Total organic carbon (TOC, [%]) content was estimated by wet oxidation with potassium dichromate ($K_2Cr_2O_7$) in a strong acid open medium ((H_2SO_4, H_3PO_4) according to Walkly-Black method as reported by NELSON and SOMMERS (1982).

Total carbon (TC) ***and total nitrogen*** (TN) content as [%] were preformed using a CHNS analyzer, in a flash combustion Thermo Finnigan, Flash 1112 Series elemental analyzer in standard mode. Ignition of 1-2 mg of fine powder wood or compost was ignited in a tin cap in O_2 at 1000° C. The oxide produced was analyzed using a thermal conductivity detector according to TABATABAI and BREMNER (1991). C:N ratio was calculated mathematically by dividing total carbon upon total nitrogen.

Humic substances, Total extractable carbon and humification parameters:

According to KONONOVA and BEL'CHIKOVA (1961) and POSNER (1966) humic acids (HA, [%]), Fulvic acids (FA, [%]), and Total extractable carbon (TEC, [%]) were extracted with a 0.1N $NaOH/Na_4P_2O_7$ solution at extraction ratio of 1:20 (compost: solution, w/v). The mixture was shaken for three hrs and left for 24 hours and centrifuged (6000 rpm) for 30 min. The TEC was determined in supernatant by mineralization at 160° C for ten minutes with 5 ml of 2 N $K_2Cr_2O_7$ solution (SPRINGER & KLEE, 1954). A liquid part of the supernatant 10 ml was carefully transferred into a glass beaker, acidified with H_2SO_4 1N (pH 2) until easy turbidity exist-remains, Afterwards the solution evaporated on the water bath to drying and the C-content (HA+FA) is determined with wet oxidation according to SPRINGER and KLEE (1954). For the determination of humic acid HA, liquid part of supernatant 25 ml was taken into beaker and 10% conc. sulfuric acid are added, until one with agitate exist-lasting turbidity occurs. Afterwards depending upon the relatives excerpt-mixes still 5 to 10 ml 10 % conc. sulfuric acid caused will added as amore. The samples were heated to 80° C for 30 min and leaves untouched for complete flocculation over night with room temperature and then centrifuged for 30 min at 8000 rpm. The precipitate (humic acids) was separated from fulvic acids and dissolved in hot 0.1M NaOH and then distilled water .The C-content of humic acid solution was then determined as explained previously. FA is estimated by subtracting the HA from the summation of (HA+FA). Degree of humification (DH), humification rate (HR), and humification index (HI) for assessment of organic matter stabilization in compost were so calculated using the following equations (Eq. 3.8, 3.9, 3.10) suggested by CIAVATTA et al. (1990).

$$DH\ (\%) = 100\ (HA + FA)/TEC \quad \text{(Eq. 3.8)} \qquad HR(\%) = 100(HA + FA)/TOC \quad \text{(Eq. 3.9)}$$

$$HI = NH/(HA + FA) \quad \text{(Eq. 3.10)} \qquad \text{Where: } NH = TEC - (HA + FA)$$

Total macro-micro nutrients (K, Ca, Mg, Fe, Cu, Mn, and Zn) as [mg kg^{-1}] were measured by atomic adsorption spectrophotometer (AAS 1100B Perkin-Elmer) according the methods described by HAVEZOV (1996) after the sample digestion using the aqua regia method (DIN ISO 11466, 1997). The total concentration of phosphorus (P, [mg kg^{-1}]) was determined in the same digestion solution by spectrophotometer at wavelength 665nm according to ascorbic acid-reduced molybdophosphoric blue method (RODRIGUEZ et al., 1994).

Available macro-micro nutrients (K, Ca, Mg, Fe, Cu, Mn, and Zn) as [mg kg^{-1}] were measured by atomic adsorption spectrophotometer after the sample extracted by ammonium acetate-EDTA (ethylene diamine tetra acetic acid) extraction solution according methods describe by COTTENIE et al. (1982). Available P was estimated according to BRAY and KURTZ (1945). Available nitrogen was extracted by 2.0 M KCl solution and analyzed calorimetrically (DAHNKE, 1990).

3.1.3.3. Thermal analysis

At the end of compost experiments some samples of the final product were selected to study the organic matter stability by using Thermogravimetric (TG) and different thermal analysis (DTA) (Fig. 3.5). The most common methods used are record transformations by means of the temperature either of mass, energy, or the mechanical properties of the samples. TG and DTA methods are based on programmed heating of the sample in a controlled atmosphere. Simultaneously thermal tests were performed on a thermo balance L81Fa (Linseis, Germany) in vertical operation mode, using platinum crucibles. The conditions were: heating rate of 10°C min^{-1} from 20 to 800° C under dynamic air atmosphere (100 ml min^{-1}). The reference material for the compost DTA-measurements was ignited Al_2O_3. For more clarification, the Thermostability of compost was compared with those in soil sample obtained from Niedermoor area (0-30 cm), Potsdam. This soil characterized by 9.63 % organic matter content. For interpretation the special software STA (TG measurement) and Linseis (DTA measurement) were used (FRIEDRICH et al., 1996). According to PANSU and GAUTHEYROU (2006) 2-3 g of air dried soil (reference) and or compost samples were crushed to 0.1 mm in an agate mortar, oven dried at 70° C for 4 h and cooling in the desiccator for 48 h (relative moisture should be 56 % at 20° C at normal pressure), This treatment homogenizes the hydration layers of any interlayer cations that may be present. The sample (20 mg) was put in the platinum crucible. Adjust the lid of the crucible so it covers approximately 2/3 of the crucible and adjust the position of the sample to that of the measurement thermocouple in the furnace. In addition to evaluate the effect of charcoal as a source of carbon on compost stability just one vermicompost sample was mixed by 0.0, 3.0, 6.0, and 12.5 % rates of crushed charcoal. The same procedure was conducted in soil and compost samples will follow with the compost treated with charcoal.

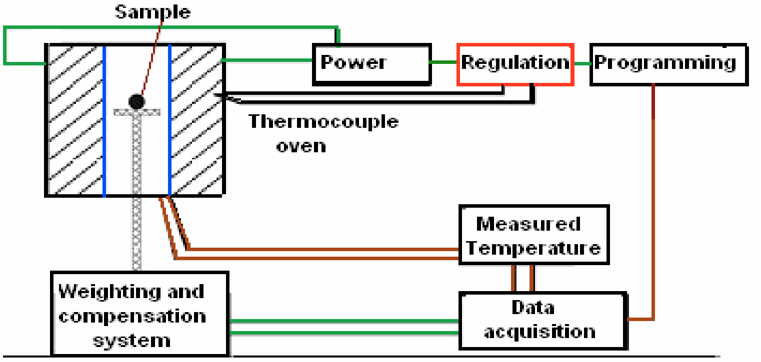

Fig. 3.5: Example of a system for thermogravimetric analysis (after PANSU & GAUTHEYROU, 2006)

3.1.3.4. Microstructure analysis

Scanning electron microscopy (SEM) was done with a CamScan CS 44 (FEI Quanta 200 ESEM with integrated Oxford Inca Energy 200 X-sight EDS system, North West University Potchefstroom Campus, South Africa). Some vermicompost samples from final product of both compost experiments were selected to study the microstructure under SEM. For more clarification the vermicompost samples were compared with soil sample. The used soil sample as a reference is the same soil used in thermal analysis (see paragraph 3.1.4.3). The samples were air dried and sieved through a 2 mm sieve. The sample grains are connected with a self-adhesive C tape attached to the Al holder and then under SEM. The specimen must be under high vacuum in the SEM system, without this high vacuum the tungsten filament will burn out. The SEM micrographs were obtained at 15 keV at a working distance of 10 mm. Monochrome photographs were taken with a small picture reflex camera, which is integrated into the CamScan CS 44 working station as an external unit. A detailed description of SEM and microanalysis is given by REED (1996). The scanning electron micrographs were assayed and described according to terminology developed by BULLOCK et al. (1984).

3.2. Plant experiments

3.2.1. Greenhouse plant experiment

3.2.1.1. Collection and preparing soil and vermicompost

The utilizing soil (tertiary sand) was collected from the surface layer (0-30 cm) of Lusatia lignite region, Germany. Soil samples were collected from different places and then mixed well to make a representative sample of the site (the sit described in paragraph 3.2.2.1). The representative soil sample was analyzed according to the international methods (see paragraph 3.2.1.3.) and the obtained data were recovered in Table 3.5. The used vermicompost was the successful wood vermicompost produced from the first compost trial (*Quercus rubra*). Different vermicompost treatments of *QR* were mixed and sieved through a 2 mm sieve to remove the residual wood. The analysis of the used vermicompost was listed in Table (3.5).

3.2.1.2. Experimental design and procedure

Pots experiment was carried out at July/2008 in greenhouse using a plastic pot of 18.7 cm diameter and 21.8 cm depth. The used soil was mixed with the wood vermicompost at mixed ratio of 0.0, 3.0, 12.5 and 25.0 % (dry weight bases, w/w). Eight pots for each mixing ratio were filled to a depth of 18 cm. The pots were arranged in ***one way completely randomized design***. Each pot was sowed by 0.4 gm seeds of *RSM* 7.2.1.grass mixed from 45 % *Festuca ovina duriuscula*, 10 % *Festuca rubra commutata*, 15 % *Festuca rubra rubra*, 15% *Festuca rubra trichophylla* and 15 % *Lolium perenne*. *RSM* 7.2.1 was appointed in the operating plan of closure of company LMBV, that they use it as standard sowings for the dry region with the optimum quantity of 20 [gm m^{-2}]. Every 3 days, the pots were irrigated at 60 % water holding capacity by using tap water.

3.2.1.3. Soil sampling and analyses

At the end of experiment (42 day from sowing) the soil of each pot after plant harvesting and both soil and vermicompost at the beginning were taken, air-dried, ground, crushed, sieved through a 2 mm sieve and kept for different chemical and physical analysis.

Table 3.5: Some physical and chemical properties of the studied soil and the used vermicompost

Properties	Soil	Vermicompost	Properties		Soil	Vermicompost
WHC [%]	30.00	165.00	C:N ratio		31.00	12.04
BD [g cm^{-3}]	1.34	0.56	TS [%]		0.22	0.76
PD [g cm^{-3}]	2.40	1.47	Total nutrients [mg kg^{-1}]	P	298.29	432.67
TP [%]	44.17	61.90		K	6725.15	11034.28
EC [dS m^{-1}]	0.19	3.19		Ca	3312.60	12023.00
pH-value [-]	3.60	7.48		Mg	1966.03	2235.00
OM [%]	2.43	27.18		Fe	803.10	6593.75
TOC [%]	1.22	13.59		Cu	11.50	18.25
TC [g kg^{-1}]	12.40	150.50		Zn	75.70	93.75
TN [g kg^{-1}]	0.40	12.50		Mn	269.50	515.00

Water holding capacity (WHC, [%]) was measured according to DEWIS and FREITES (1970). Dray Bulk density (BD) as [g cm^{-3}] was measurement according the method describe by BLAKE (1965). Also, dray particle density (PD) as [g cm^{-3}] was determined according to BLAKE and HARTAGE (1986). Total porosity (*TP*) was calculated using the following equation (Eq. 3.11):

$$TP\ (\%) = 100 \times \left[1 - (BD/PD)\right] \qquad \text{(Eq. 3.11)}$$

The pH value and soil acid-base buffering capacity: pH value was measured in soil $CaCl_2$ 0.01M suspension (1:5 w/v) after shaking and letting for 30 min by pH meter according to DIN ISO 10390 (2002). The pH was determined in vermicompost as shown previously in paragraph (3.1.4.2.). Soil acid-base buffering capacity was measured and buffer curves were drawn according to Arrhenius with Brenner and Kappen modification (OSTROWSKA et al., 1991) by adding increasing amounts of 0.1 mol HCl dm^{-3} and 0.1 mol NaOH dm^{-3} to soil samples, which, after 24 hours, was followed by potentiometric pH measurements.

Electrical conductivity (EC, [dS m^{-1}]) was measured using electrical conductivity apparatus in the soil extraction solution at 1:5 soils: distilled water (w/v) ratio according to DIN ISO 11265 (1997). The EC was determined in compost as shown previously in paragraph (3.1.4.2.).

Organic matter (OM) content as [%] was determined by weight loss on ignition at 550° C according to DIN 19684-3 (2000).

Total organic carbon (TOC) content as [%] was estimated by wet oxidation with potassium dichromate ($K_2Cr_2O_7$) in a strong acid open medium ((H_2SO_4, H_3PO_4) according to Walkly-Black method as reported by NELSON and SOMMERS (1982).

Potential and effective cation exchange capacity (PCEC, ECEC) as [cmol kg^{-1}] were determined by using the unbuffered methods (0.1M $Bacl_2$ methods) according to HENDERSHOT and DUQUETTE (1986). ECEC was calculated from the summation of basic and acidic cations (TEB+TEA) in leachate solution after treated by $BaCl_2$ solution, shaking, centrifuging (5000 rpm) and collecting in volumetric flask and then determine (Ca, Mg, K, Na) by atomic adsorption spectrophotometer (HAVEZOV, 1996). PCEC was measured by estimated Ba expelled by $CaCl_2$ 0.1M in the collecting solution (see Eq. 3.7).

Total exchangeable acidity (TEA) as [cmol kg^{-1}] was measured in barium chloride 0.1 M extraction solution according to Expert Panel on Soil (2003). 5 g of air dried soil was leached by 30 mL of 0.1 M barium chloride then shaking, centrifuge (5000 rpm) and the supernatant collected in 100 ml volumetric flask. Repeat by adding 30 mL aliquots of $BaCl_2$ solution shaking, centrifuging, and decanting two more times, collecting all the supernatant in the same 100 mL volumetric. The concentration of exchangeable acidity is calculated from the amount of standard NaOH needed to back titration the leachate to the first permanent pink endpoint after adding phenolphthalein indicator. The following equations (Eq. 3.12, 3.13) were used to calculate ECEC and base saturation (BS):

$$ECEC(cmol \cdot kg^{-1}) = TEB + TEA \qquad \text{(Eq. 3.12)} \qquad BS\ (\%) = (TEB / ECEC) \times 100 \qquad \text{(Eq. 3.13)}$$

Total sulphur (TS), ***total carbon*** (TC) and ***total nitrogen*** (TN) content as [%] were preformed using a CHNS analyzer according to TABATABAI and BREMNER (1991) as described in paragraph (3.1.4.2.). C:N ratio was calculated mathematically by dividing total carbon upon total nitrogen.

Total macro and micronutrients (K, Ca, Mg, Cu, Fe, Mn, and Zn) in soil and compost at the beginning were measured according to the methods described by HAVEZOV (1996) after digested 5 g soil or compost with 10 ml of H_2SO_4-$HClO_4$ acid Conc. 3:1 (v/v) mixture until the digestion solution become colorless according to JACKSON (1967). Total P was determined in the same digestion solution by spectrophotometer at wavelength 665nm according to ascorbic acid methods (RODRIGUEZ et al., 1994).

Available macro and micro nutrients: In due to soil is acidity the available P was extracted by Acid-Fluoride solution (0.025 M HCl and 0.030 M NH_4F) according to BRAY and KURTZ (1945). The extracted P was determined using a spectrophotometer at wav length 665 nm using ascorbic acid method (RODRIGUEZ et al., 1994). Available nitrogen was extracted by 2.0 M KCl solution and analyzed calorimetrically (DAHNKE, 1990). The available macro-micro nutrients of K, Ca, Mg, Cu, Fe, Mn, and Zn were extracted by ammonium acetate-EDTA (ethylene diamine tetra acetic acid) extraction solution according methods describe by COTTENIE et al. (1982). The extracted solution were tested for macro-micro nutrients using atomic absorption spectrometry (AAS 1100B Perkin-Elmer) according the methods described by HAVEZOV (1996).

3.2.1.4. Planting measurements and analyses

At the end of the experiment (42 day from sowing), the plants of each pot were harvested. The harvested plants were washed by water until become free from any soil particles. The number of plants and its height of each pot were measured and recorded. The plants of each pot (roots + straw) were weighted to measure the fresh weight, after straw separated from the roots. Then the plants air-dried, oven dried at 70° C for 48 hr to obtain on dry matter yield. Relative increase (*RI,* [%]) and its agronomic efficiency (*AE*) of both straw and roots of the plants were calculated using the following formulas (Eq. 3.14, 3.15), where the R_T is the fresh or dray matter yield weight of treated plants, *RC* is the fresh or dry matter yield weight of control, *AT* is the fresh or dray matter yield weight of treated plants, *AC* is the fresh or dry matter yield weight of control, and *P* is the application rate of compost [%].

$$R_I(\%) = 100\times(R_T - R_C)/R_C \qquad \text{(Eq. 3.14)} \qquad A_E = (A_T - A_C)/P \qquad \text{(Eq. 3.15)}$$

Chemical composition of plant: The total N was determined according the methods described above (TABATABAI & BREMNER, 1991). The total content of macro-micro nutrients (P, K, Ca, Mg, Fe, Cu, Mn, and Zn) were determined by atomic absorption spectrometry (AAS 1100B Perkin-Elmer) according to the methods described by HAVEZOV (1996) after extracted by digesting 0.2 g for the plants in all treatments at the end of experiment with 10 ml of H_2SO_4-$HClO_4$ acid Conc. 3:1 (v/v) mixture until the digestion solution become colorless (JACKSON, 1967), except the phosphorus which it was measured using a spectrophotometer (RODRIGUEZ et al., 1994).

3.2.2. Field plant experiments

3.2.2.1. Study areas

The experiment was established in two sites of Lusatian open-cast lignite mining region (coal mine waste), Saxony state, Germany (see figure 3.6). The first location was tertiary sand and located on Bergen grazing land (TM 25: Sheet 4551 Hoyerswerda town) and Gauss-Krueger coordinates (R=5 447 250 m, H=5 706 900 m). The soil characterized by high geogenic organic matter content, low pH, low content of plant nutrition, low CEC and recent OM. The second location was quaternary sand which located on the employer prospective area along the banks and shores of Neuwieser lake (TM25: Sheet 4550 Lauta town (10 km west of Hoyerswerda) and Gauss-Krueger coordinates (R=5 436 500 m, H=5 704 750 m). The soil characterized by low pH value, OM, and CEC contents. The mean Annual temperature is 9.4° C and the mean annual precipitation is 576 mm in both sites. The studied soils were analyzed for some chemical and physical properties as shown in Table 3.6.

3.2.2.2. Experimental design and procedure

In both locations two types of soil conditioners were used to study their effect on physical and chemical characteristics of soil, as well as the response of plants grown in these soils for these conditioners. The first amelioration was the compost produced from second compost experiment (*QR* wood). At the end of experiment all compost treatments were air dried, sieved to remove the residual of wood, mixed together and then kept until added to the soil in both locations. The chemical properties of wood compost were recorded in Table 3.6. While the second used type is called Arkadolith (ARK). The ARK is an inorganic component characterized by high ability to absorb and maintain water. Also he is able to improve soil physical properties.

The field experiments were started in 04/04/2009 in both sites. The utilized soil amendments were mixed with soil in both locations to a depth of 50 cm. The soil was dug, transported out of the plots, mixed with the used ameliorations and then returned again to the plots after separated the plots by the plastic. The area of every plot (treatment) in tertiary sand experiment was (2 m length and 1 m wide), while it was 1.4 m length and 1.4 m wide in quaternary sand trial. The distance between the experimental units was 30 cm. The different soil treatments were arranged in ***split plot design*** as shown in Table 3.7. Every treatment was classified in two sub plot, the first sub plot cultivated by *RSM* 7.2.1 grass (see paragraph 3.2.1.2) while the second sub plot sowed by the autochthonous (Autoch) grass. The autochthonous grass is a mixture of different species of *Agrostis capillaries, Arenaria serpyllifolia, Artemisia campestris, Corynophorus canescens, Euphorbia cyparissias, Hypericum perforatum, Hypochoeris radicata, Jasione montana, Rumex acetosella, Sedum acre, Thymus serpyllum, Trifolium arvense and Trifolium campestre*. The used grasses were sowed at the rate of 20 [gm m^{-2}]. Irrigation in this experiments relied on the rain.

3.2.2.3. Soil sampling and analyses

The experiments were monitored about six months (04/04 to 04.10.2009) and ended with the end of the growing season for grass. At the end of the experiment soil samples of each site in all treatments were taken, air dried, crushed, sieved through a 2 mm sieve and kept for some chemical and physical analysis. The determined soil chemical analyses were pH, EC, OM, TC, TN, and C:N ratio (see paragraph 3.2.1.3). Cation exchange capacity (CEC) was estimated by $BaCl_2$ method according to HENDERSHOT and DUQUETTE (1986). Bulk density was estimated as shown previously according to BLAKE (1965). Also, water holding capacity was measured according to DEWIS and FREITES (1970). Soil particle distribution of the studied soil (only at the beginning of experiment) was measured according the pipette methods described by DAY (1965).

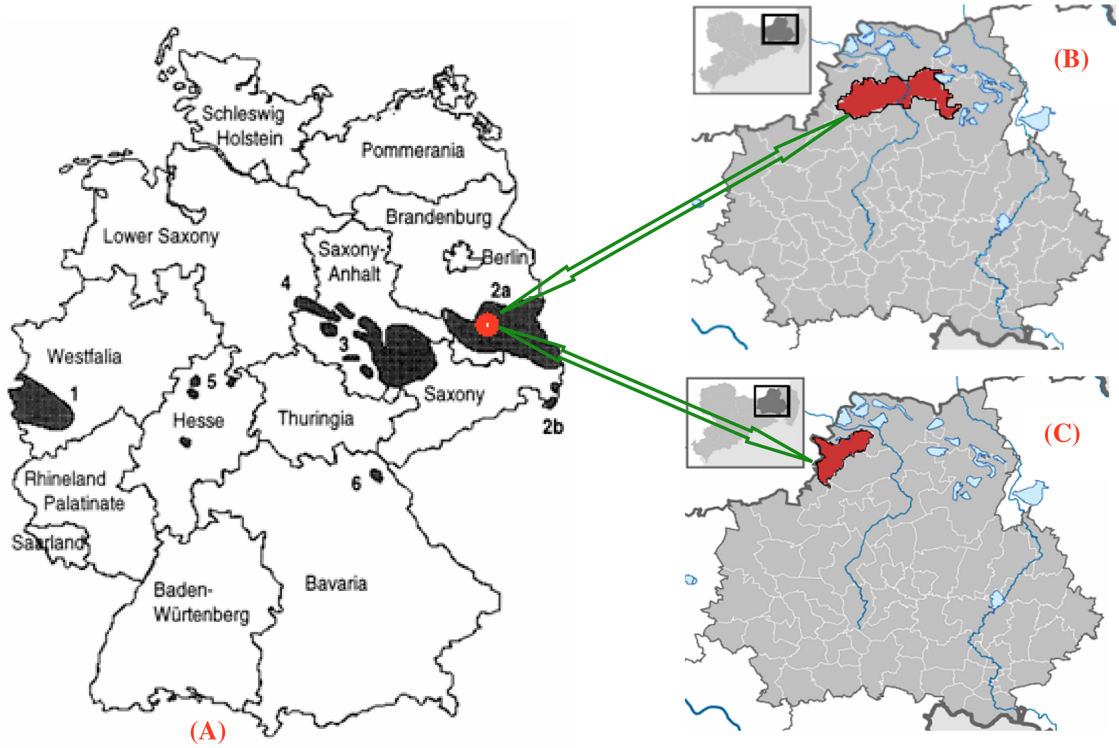

Fig. 3.6: Geographical location of the studied soils

(A) = Lusatian lignite region (lower Lusatia 2a and upper Lusatia 2b)
(B) = Tertiary sand, and
(C) = Quaternary sand

3.2.2.4. Planting measurements and analysis

At the end of experiment in both sites the following planting parameters were measured:

1) Height [cm]
2) Covering percentage [%]
3) Fresh and dry matter yield of the grasses were estimated. The grass were cutting above soil surface(straw) and kept in plastic pages, also representative samples of sub-surface biomass (root) were taken. The straw samples were taken to lab and prepared to estimate fresh and dry matter yield [g m^{-2}]. While only the dry matter yield of root was measured.

3.3. Statistical analysis

The most appropriate method of statistical analysis of such experiments is analysis of variance (ANOVA). Analysis of variance is the most effective method of analyzing more complex data sets. It is, however, a method comprising many different variations. Therefore, the obtained data were statistically analyzed using this technique (ANOVA). This technique was used to examine the significance level of the studied factors in compost, soil and plant characteristics. Physicochemical properties of compost and soil and all determinations of plant were measured on dry weight bases. The treatment means were compared using LSD (Least Significance Difference) range test at 5 % level of probability according to Snedecor and Cochran (1989). Correlation coefficient analysis was also carried out on the data to see the trend of relationships between compost application rates and some plant growth parameters. All statistical analyses were done with COSTAT software package (Version 6.311, Monterey, CA, USA) on a personal computer.

Table 3.6: Some chemical and physical properties of the studied soils and wood compost

Properties	**Tertiary sand**	**Quaternary sand**	**Compost**
pH-value [-]	3.60	4.00	7.68
EC [dS m^{-1}]	0.19	0.07	4.26
OM [%]	2.45	0.75	36.72
CEC [cmol kg^{-1}]	3.45	3.11	46.37
TC [g kg^{-1}]	12.28	4.70	29.38
TN [g kg^{-1}]	0.40	0.20	1.76
DBD [g m^{-3}]	1.34	1.57	0.56
Sand [%]	90.00	92.00	-
Silt [%]	5.80	1.80	-
Clay [%]	1.20	0.20	-
Gravels [%]	3.00	6.00	-
Texture type	Sandy	Sandy	-

EC = Electrical conductivity, OM = Organic matter, CEC = cation exchange capacity, TC = Total carbon, TN = Total nitrogen, DBD = Dry bulk density

Table 3.7: The experiment design and different applied rates of compost and ARK in both locations

Treatments					
Tertiary sand			**Quaternary sand**		
Symbol	*RSM* 7.2.1 grass	Autoch grass	*RSM* 7.2.1 grass	Autoch grass	Symbol
T1	100 - 0 – 0	100 - 0 – 0	100 - 0 – 0	100 - 0 – 0	Q1
T2	97 - 0 – 3	97 - 0 – 3	90 - 5 – 5	90 - 5 – 5	Q2
T3	95 - 0 – 5	95 - 0 – 5	94 - 3 – 3	94 - 3 – 3	Q3
T4	90 - 0 – 10	90 - 0 – 10	97 – 1.5 – 1.5	97 – 1.5 – 1.5	Q4
T5	94 - 3 – 3	94 - 3 – 3	97 - 0 – 3	97 - 0 – 3	Q5
T6	90 - 5 – 5	90 - 5 – 5	98.75 - 0 – 1.25	98.75 - 0 – 1.25	Q6
T7	85 – 7.5 – 7.5	85 – 7.5 – 7.5			

The numbers in each column (plot) is the mass of raw materials [%], which arranged as: Soil – ARK component – wood compost

4. RESULTS AND DISCUSSION

4.1. Compost experiments

4.1.1. First compost experiment

4.1.1.1. Changes in temperature degree during composting period

The temperature levels of the compost pots increased and reached 32-48° C due to the energy released from biochemical reaction of microorganisms in the compost while the temperature tend to decrease after the thermophilic phase due to the loss of substrate and a decrease in microbial activity (EPSTEIN, 1997). The data as illustrated by Figure 4.1 (Table A.1 in the appendix) showed the change in the compost temperature degree [°C] as affected by the studied factors during the experiment period. These data reveals that, the temperature degree was greater affected by some factors under study and lower affected by the other factors. There are a wide variations in the measured temperature during the experiment period. It was increased up to third week (21 days) and then gradually dropped until become nearly constant at decomposition period of 10 weeks (63-70 days). It means that the compost after 10 weeks entered in stability phase. Increase temperature at the beginning may be due to high available carbon content which it provides a favorable condition for the growth and biological activity of microorganisms. These results are in agreement with the findings of NDEGWA and THOMPSON (2000). It can noticed that, the temperature did not achieve sustained to meet EPA standards of pathogen reduction which require temperatures of 55º C for three consecutive days during the coolest period of aeration, or 40º C for five consecutive days and 55° C for three consecutive days (MICHAEL & KATHLEEN, 2001; NDEGWA & THOMPSON, 2001). Lower than anticipated temperatures may have been due to the small size of pots and loss the heat by radiation to the outer space (NATHAN, 2004). Fungi have the ability to produce enzymes that are able to degrade lignin and had attributed to the reduction of easily degradable organic compounds and the subsequent decrease in bacteria. This may be one of the reasons why the compost did not reach the thermophilic stage (LAZCANO et al., 2008).

Generally under different studied treatments, temperature degree of *QR* wood compost was higher than those in *PS* wood compost as shown in Figure 4.1. This may be due to the high proportion of soluble carbon substances like hemicellulose and low amount of the hard degradation materials (lignin and cellulose) in *QR* wood compared with *PS* wood which affect on microbial activity (EILAND et al. 2001). Another reason may be lignin and cellulose is hydrophobic compounds while hemicellulose is hydrophilic. This may impact on the hardness of wood and his susceptibility to degradation by microorganisms. Regarding to the effect of water quality on the compost temperature, it can be noticed that, the compost treated by compost water characterized by high temperature degree compared with that treated by tap water. This trend indicates that, the compost water enhanced the decomposition processes by its high content of microorganisms and nutrients compared with tap water (WANG et al. 2005). Other differences of compost temperature were found with different mixed ratios of woodchips and lake mud. The high temperature degree was found in the compost of 1:3 mixed ratio (wood : mud) followed by that found at mixed ratio of 1:1 (wood : LM). These findings may be results from the high compaction of compost associated the high content of lake mud which reduced temperature loss by radiation. These results are in agreement with these obtained by (MASON & MILKE 2005; ROU 2007). Finally the data in Figure 4.1 show, under different studied mixtures the temperature degree of the treatments infected by worms did not gave clear trend. This is due to the worms added after compost entered in mesophilic phase (TAJBAKHSH et al., 2008). Moreover the worms are doing tunnels within the compost which increase the aeration and the loss of temperature.

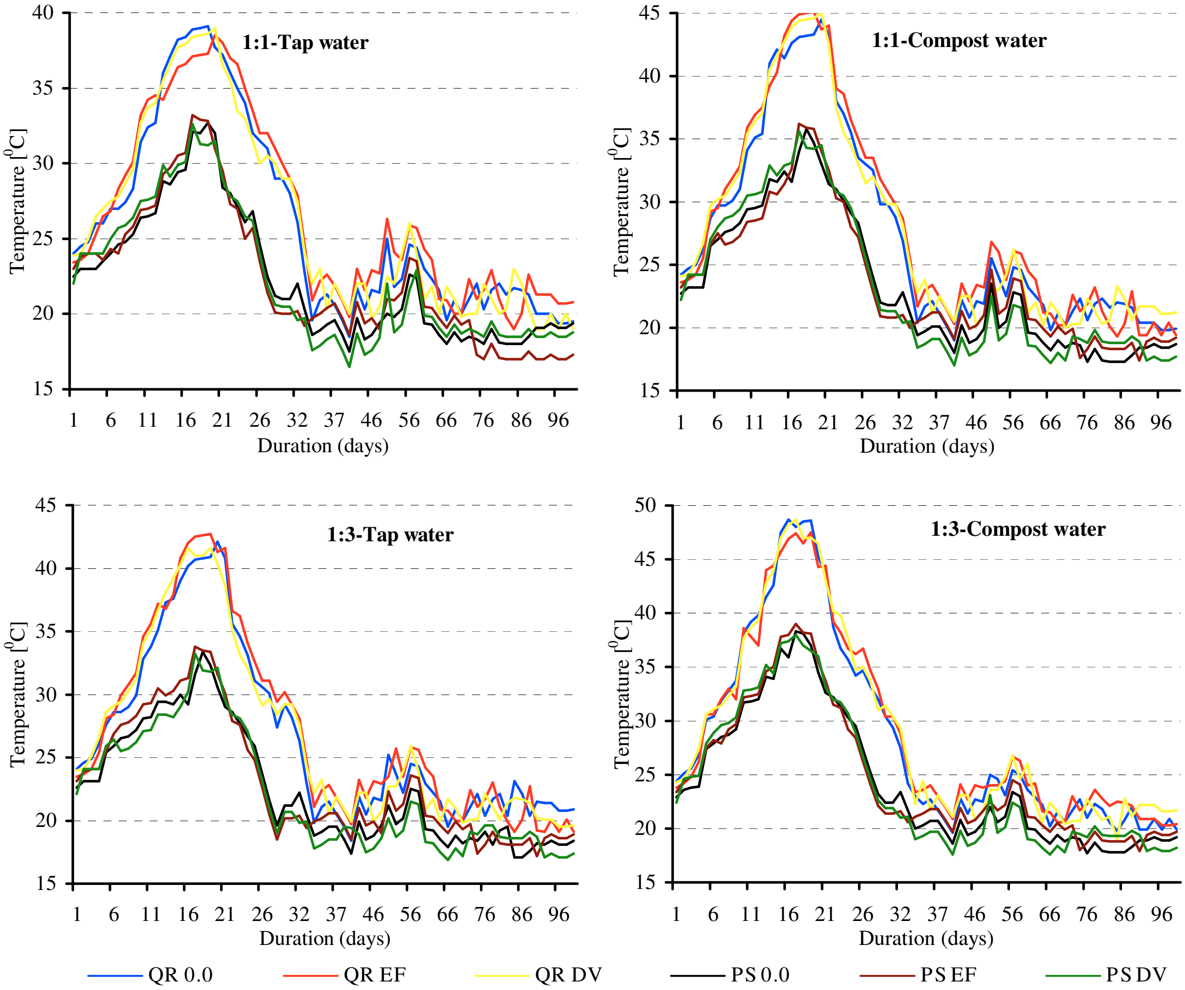

Fig. 4.1: Changes in temperature degree during composting of wood under different studied treatments (data represent averages of three replicates)

4.1.1.2. Changes in cumulative carbon dioxide during composting period

Regarding to the values of carbon dioxide (CO_2) produced from woodchips compost as illustrated by Figure 4.2 (Table A.2 in the appendix) it can be showed that, the cumulative weakly of these values [g kg^{-1}] under different experimental conditions, were increased with the increase of decomposition period up to week number three (21 days) and decreased after that till the 77th day which it was stable. This increase was found only at three week where the produced CO_2 was decreased after that up to end of the experiment. It can suggest that, if used the produced CO_2 as a function of humification rate, the high rates were presented at the first weeks of the experiment, where the low rates were found in the latter weeks. This can be explained by microbial metabolism of readily soluble carbon (sugars, carbohydrates, and hemicellulose) in the compost feedstock increases, more oxygen is consumed and carbon dioxide released. Once labile C is degraded, microbial activity slows and CO_2 decreased; the majority of the remaining carbon is in the form of lignin or cellulose. Similar results were obtained by (EILAND et al. 2001; DRUILHE et al., 2002; ADANI et al., 2004; DIMITRIS & ROBERT, 2006). The data in Figure 4.2 show that, the values of produced CO_2 [g kg^{-1}] in *QR* wood compost were higher than these of *PS* wood compost in different studied treatments. This trend may be resulted from the high content of soluble carbon of *QR* wood, compared with those of *PS* wood, where these components resulted in an increase of decomposition rates and the activity of microorganisms (SINGH & SHARMA, 2003; TIQUIA, 2005; DIMITRIS & ROBERT, 2006).

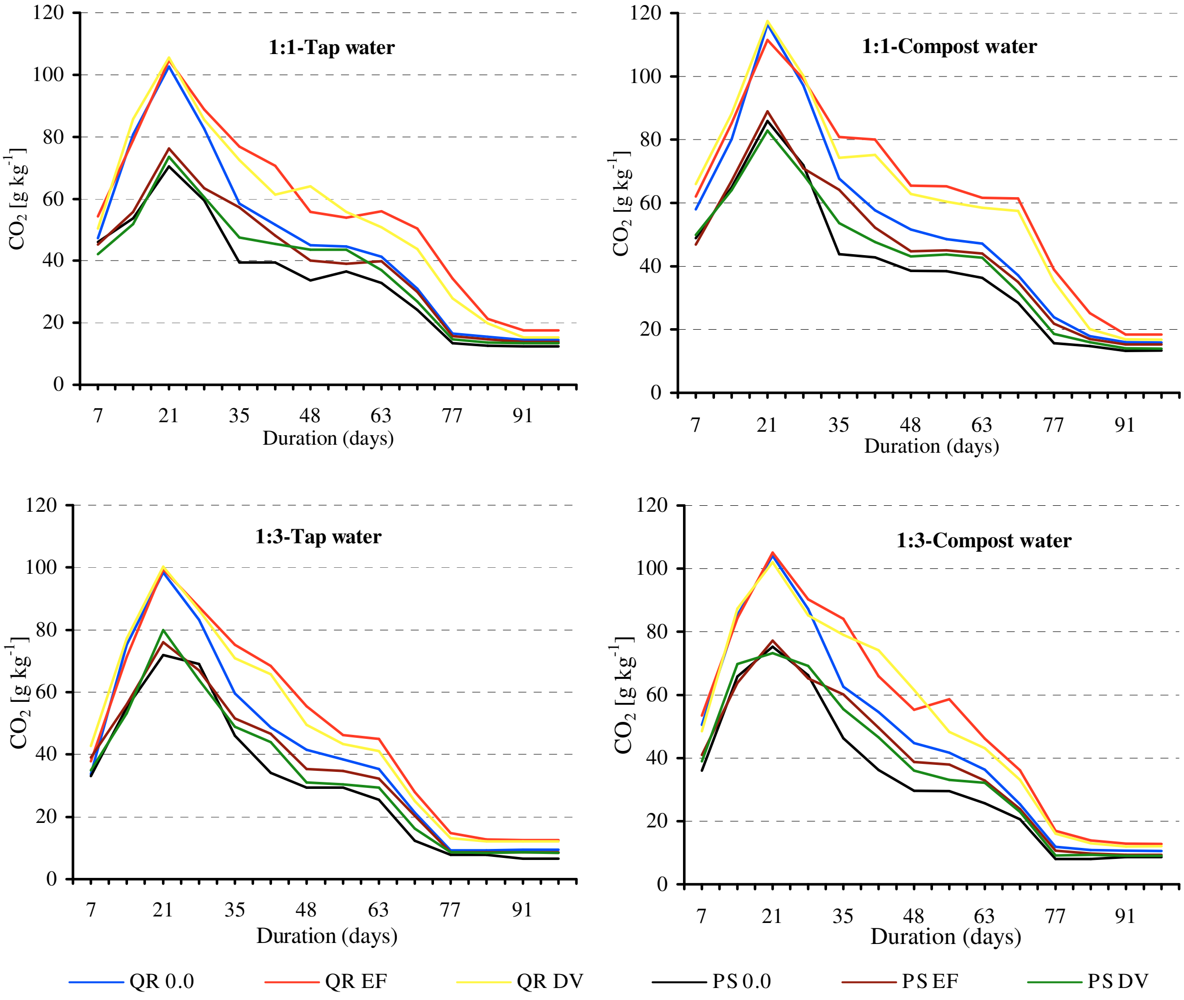

Fig. 4.2: Changes in weakly cumulative amount of CO_2 produced during composting of wood under different studied treatments (data represent averages of three replicates)

Furthermore, this trend may be due to *PS* woodchips have been more difficult in degrading by microorganisms and contain more toxic substances compared with *QR* woodchips. Also Figure 4.2 showed the efficiency of the used earthworms (*EF and DV*) on the produced CO_2 during the decomposition period was clear with the two woods, where this infection resulted in an increase of produced CO_2. Earthworms modify the substrate condition which consequently promotes the carbon losses from the substrate through microbial respiration in form of CO_2 and even through mineralization of organic matter (KAVIRAJ & SHARMA, 2003; GARG et al., 2005). These increases were higher in the treatments of *EF* worm than those associated the treatments of *DV* worm. From this trend may be suggested that, the efficiency of *EF* worm on the rate of decomposition process was higher than that found with *DV* worm under the same decomposition conditions (ATIYEH et al., 2000c). Furthermore EDWARDS (1988) found that, *DV* worm was more a large worm with a low reproductive rate and slow maturity rate compared to *EF* worm. However, comparing the reproductive capacity and maturation time with that of other vermicomposting species, *DV* worm seems to be a less successful earthworm's species for vermicomposting according to Viljoen et al. (1991, 1992). The observed difference could be attributed directly to the feeding preferences of individual earthworm species and indirectly to mutuality relationship between ingested microorganisms and intestinal mucus which might be species-specific. The clear observation which may be noticed from the data in Figure 4.2 was the compost moisted by compost water produced a high amount of CO_2 than the same treatments moisted by tap water. This trend resulted from the high content of OM, nutrients and microorganisms in compost water compared with these presented in tap water (ADANI et al., 2003; NATHAN, 2004). Finally, other differences of compost CO_2 were found with different mixed ratios of woodchips and lake mud. Unlike temperature the high amount of CO_2 was found in the compost of 1:1 mixed ratios followed by that found at mixed ratio of 1:3 (wood : LM). These findings may be results from high proportion of organic carbon (reflected by the high amount of wood) in the 1:1 mixing ratio than that in 1:3 mixing ratio.

4.1.1.3. The quantities of CO_2 produced from composting and burning wood

The cumulative amount of CO_2 producing during composting periods (100 days) and the amount of CO_2 evolved by combustion of wood are presented in Figure 4.3 (Table A.4 in the Appendix). It can be noticed that, the cumulative amount of composting CO_2 was lower than combustion CO_2. The amount of combustion CO_2 was 1860.80 and 1860.10 [g kg^{-1}] of *QR* and *PS* wood respectively. The large amount (873.40 g kg^{-1}) of composting CO_2 was in favor to *QR* wood at mixing ratio 1:1 (wood: LM), infected by *EF* worm and irrigated by compost water while the lowest value (434.60 g kg^{-1}) was recorded to *PS* wood, at mixing ratio 1:3 (wood : LM), uninfected and irrigated by tap water. So that the effect of wood composting in increasing greenhouse gases especially CO_2 was very low in compared with that produced by burning (ABRIGO, 2008; INGA & ZENONAS, 2008).

On the other side it should be calculate the participated of wood in producing CO_2 during composting, because the produced CO_2 during composting did not come only from the wood, but resulted from both the organic carbon (OC) of the wood and lake mud. So that, the amount of CO_2 produced from wood can be calculated in depending on the amount of OC in both wood and LM (Table 3.1). The difference between CO_2 produced from degradation organic carbon of wood only and the other amount of CO_2 evolved from burning wood is the stored CO_2 in compost. The calculation is dependent on assumed that, the equal impact of microbial activity on organic carbon degradation for both wood and lake mud. For example, the average of cumulative amount of CO_2 produced from 100 g *QR* wood in 1:1 mixed ratio and irrigated by tap water is 112.62 g. This quantity of CO_2 formed about 60.54 %⁽¹⁾ from the amount of CO_2 evolved by burning 100 g wood (Fig. 4.4-a). So that the stored CO_2 in compost instead of emission to atmosphere is 39.46 % (100 – 60.54) as shown in *QR* wood (1WC:1LM) Figure 4.4-(a). The relative percentage of cumulative amount of CO_2 produced during composting and the residual percentage of CO_2 which storage in compost are showed in Figure 4.4. Also data in Figure 4.4 showed different contributions of wood composting in CO_2 emission reducing under different studied treatments. Generally, the percentage of stored CO_2 in *QR* wood compost is lower than *PS* wood compost. These results could be related to low biodegradation and humification rates of *PS* wood and consequently low amount of CO_2 produced by microbial activity in comparison by *QR* wood. Regarding to the effect of different mixed ratios, under different treatments the 1:1 mixing ratio (wood : LM) restore more amount of CO_2. The stored CO_2 in the treatments irrigated by tap water is higher than those irrigated by compost water. This also reflects the microbial activity of compost water treatments that produced the bigger amount of CO_2.

Finally it was clear that, disposal of wood and its wastes by composting instead of burning is a good tool that may be will use in the future to reduce CO_2 emission. In addition the stored CO_2 in form of organic carbon and other fertility factors in the wood compost will improve the extreme soil characteristics after his applications. Moreover, the remaining organic carbon stored in the compost without turning into CO_2 is characterized by a high degree of stability (CIAVATTA et al., 1993; MONDINI et al., 2003). Therefore the addition of this compost will increase the survival period of organic matter and its benefits in the soil.

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(1) = ([112.62 / 186.08] x 100)

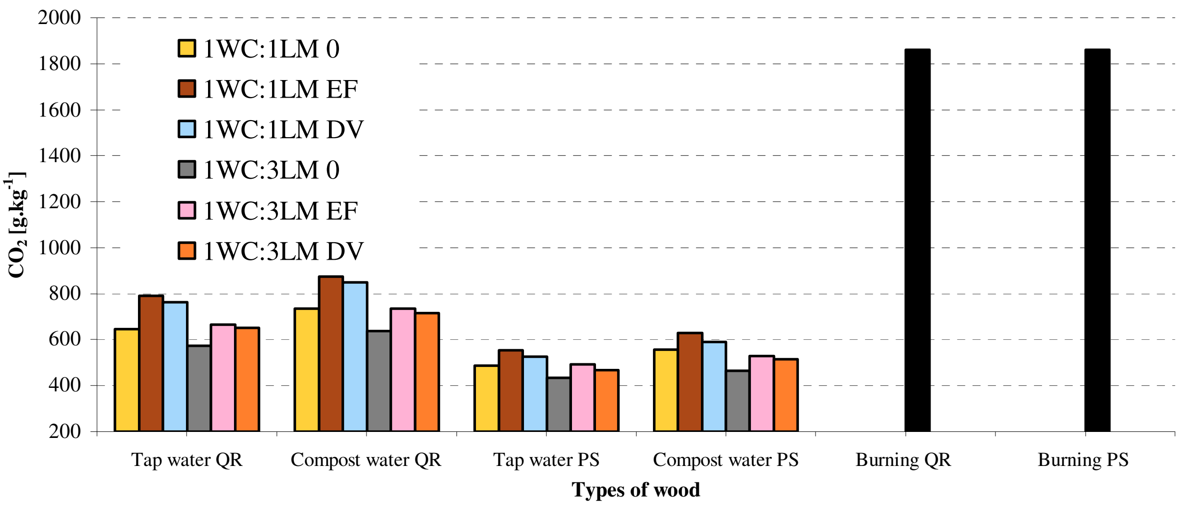


Fig. 4.3: Cumulative amount of CO_2 during composting period and the other CO_2 evolved by burning wood

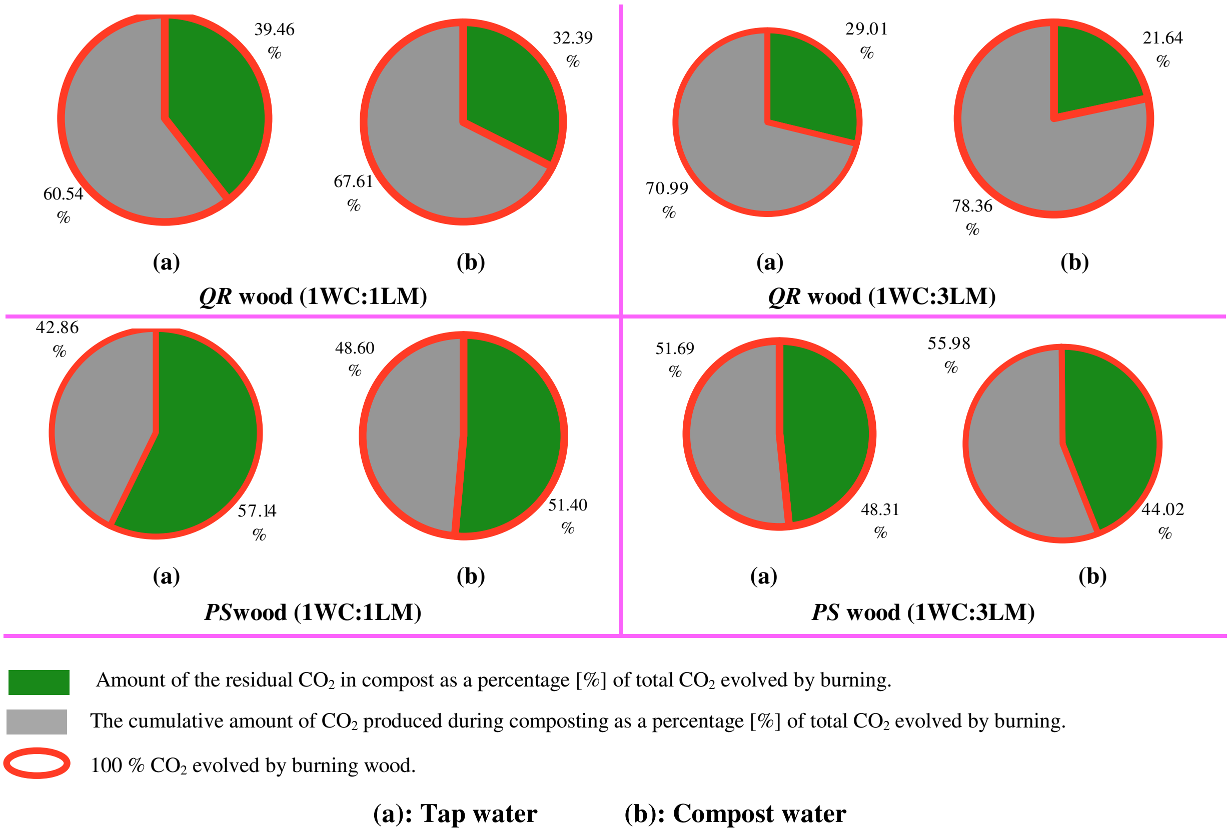
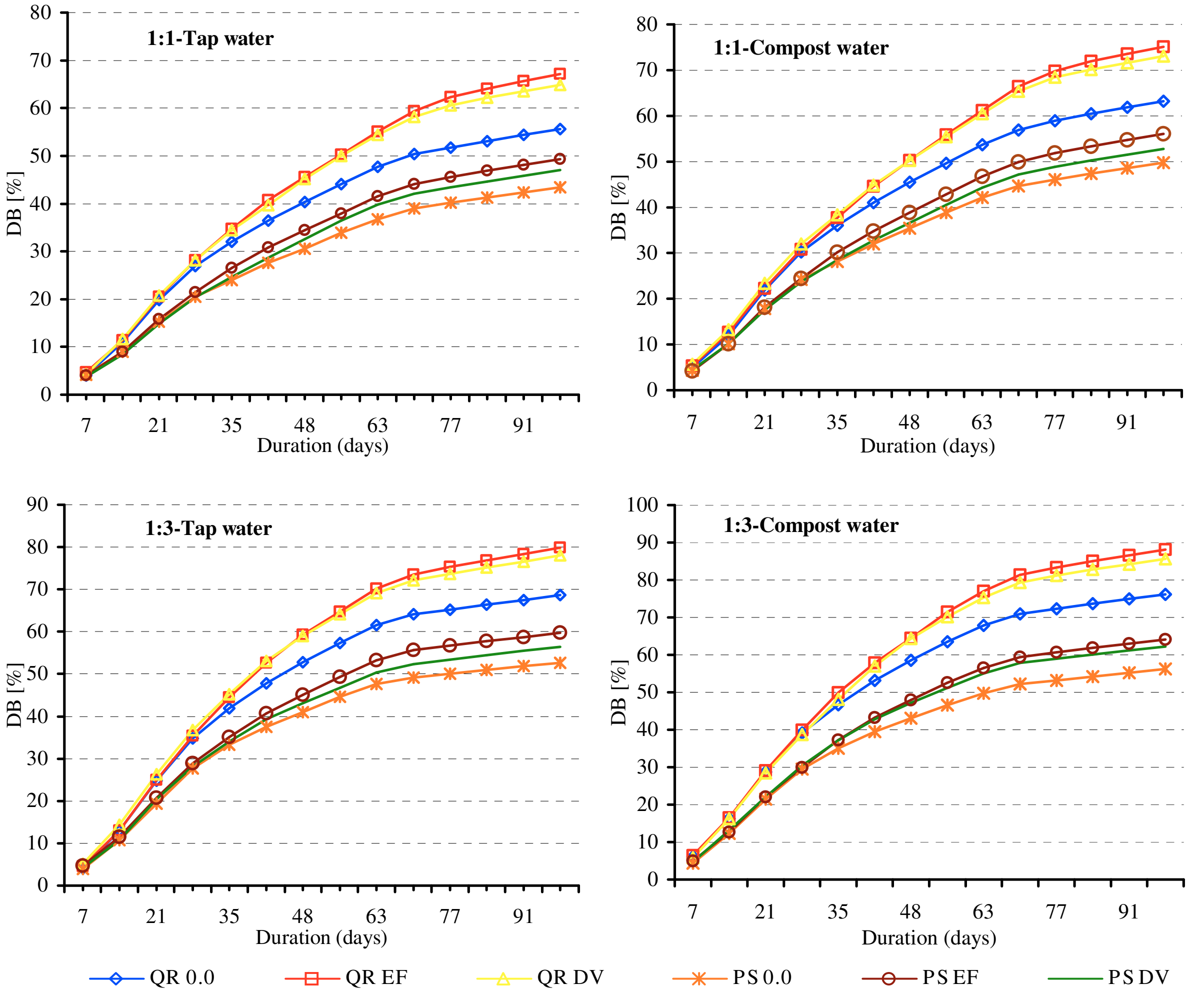


Fig. 4.4: Relative percentage of the Cumulative CO_2 produced during composting period and the residual CO_2 storage in compost to CO_2 evolved by burning wood

4.1.1.4. Degree of biodegradation

Under aerobic conditions, the carbon is biologically oxidized to CO_2 inside the cell releasing energy that is harnessed by microorganisms for its life processes. Thus, a measure of the rate and amount of CO_2 evolved as a function of TOC input to the composting is a direct measure of the amount of substrate being utilized by the microorganisms (biodegradation present). Hence, to evaluate the microbial activity and the Susceptibility of wood for decomposition, it should be measured by estimating the biodegradation degree during composting. Therefore, the biodegradation degree (DB) of wood compost was calculated depending on the theoretical amount of CO_2 (assuming that all the OC of the test material is transformed into CO_2) and cumulative amount of CO_2 produced during composting period (Tables A.3 and A.4). The calculated values [%] of DB of the used woods as a compost material, and also as affected by the studied factors was illustrated by Figure 4.5 (Table A.5). These values showed the DB of *QR* wood compost was higher than that of *PS* wood compost. This may be due to the ability of microorganisms on the degradation of *QR* wood was higher than *PS* wood. This trend was formed with all treatments under study. Also, the values of DB ware increased with the increase of incubation period, particularly at the first period of experiment. Of course because of the increased amount of CO_2 accumulated in this period (DIMITRIS & ROBERT, 2006). This increase is very small after the day 70, where it means the compost entered in stability phase. This trend could be related to the high amount of easily soluble carbon in the beginning of the experiment compared with their counterparts at the end of the experiment, which affect the biological activity (NDEGWA & THOMPSON, 2000; TUOMELA et al., 2000; TIQUIA, 2005).


1:1-Tap water

1:1-Compost water

1:3-Tap water

1:3-Compost water

Fig. 4.5: Changes in degree of biodegradation during composting of wood under different studied treatments (data represent averages of three replicates)

Regarding to the effect of water quality on the DB the recorded data showed the treatments moisted by compost water have a high values of DB compared to these observed in tap water treatments. The compost water enhanced the processes of biodegradation than tap water. This is apparently may be because compost water contains a high amount of macro-micro-nutrients and microorganisms compared with these presented in tap water (ROMERO et al. 2001). Also, the obtained data show the greater effect of mixed ratio of wood and mud on the values of biodegradation degree. Although the CO_2 produced from 1:1 was higher than 1:3 mixing ratios (wood : LM), however the biodegradation degree of 1:3 is higher than 1:1 under different studied treatments. This trend is due to the small amount of theoretical CO_2 of compost material in 1:3 mixing ratio compared with the mixture of 1:1. In addition this may be related to the high content of N, P and other nutrients in mud compared with presented in wood which it was a good environment for the growth and nutrition of microorganisms (ADANI et al. 2003; WANG et al. 2005). Finally greater effect for the inoculated worms on the degree of biodegradation was found, where the high values ware associated the infection with *EF* worm and the lowest were noticeable in the uninfected treatments. This may be due to the high ability of *EF* worms to break and digest the wood, which prepares suitable conditions for growth and presence a large number of microorganisms (SINGH & SHARMA, 2003; KAUSHIK & GARG, 2004).

4.1.1.5. Organic matter, total organic carbon and total extractable carbon

Organic matter content of different compost treatments can be seen in Figure 4.6 (Table A.6 in the appendix). The relative decrease of the OM content [%] through the degradation of the compost materials were varied widely as affected by the tested factors where this content was varied from more than 65.0 % to lower than 20.0 %. The relationships between the prepared compost content of OM and the incubation period was negative. This trend was resulted from the increase of decomposition and degradation of wood organic matter with the increase of incubation period (NATHAN, 2004; ZHANG & HE, 2006; ROU, 2007; LECONTE et al., 2009).

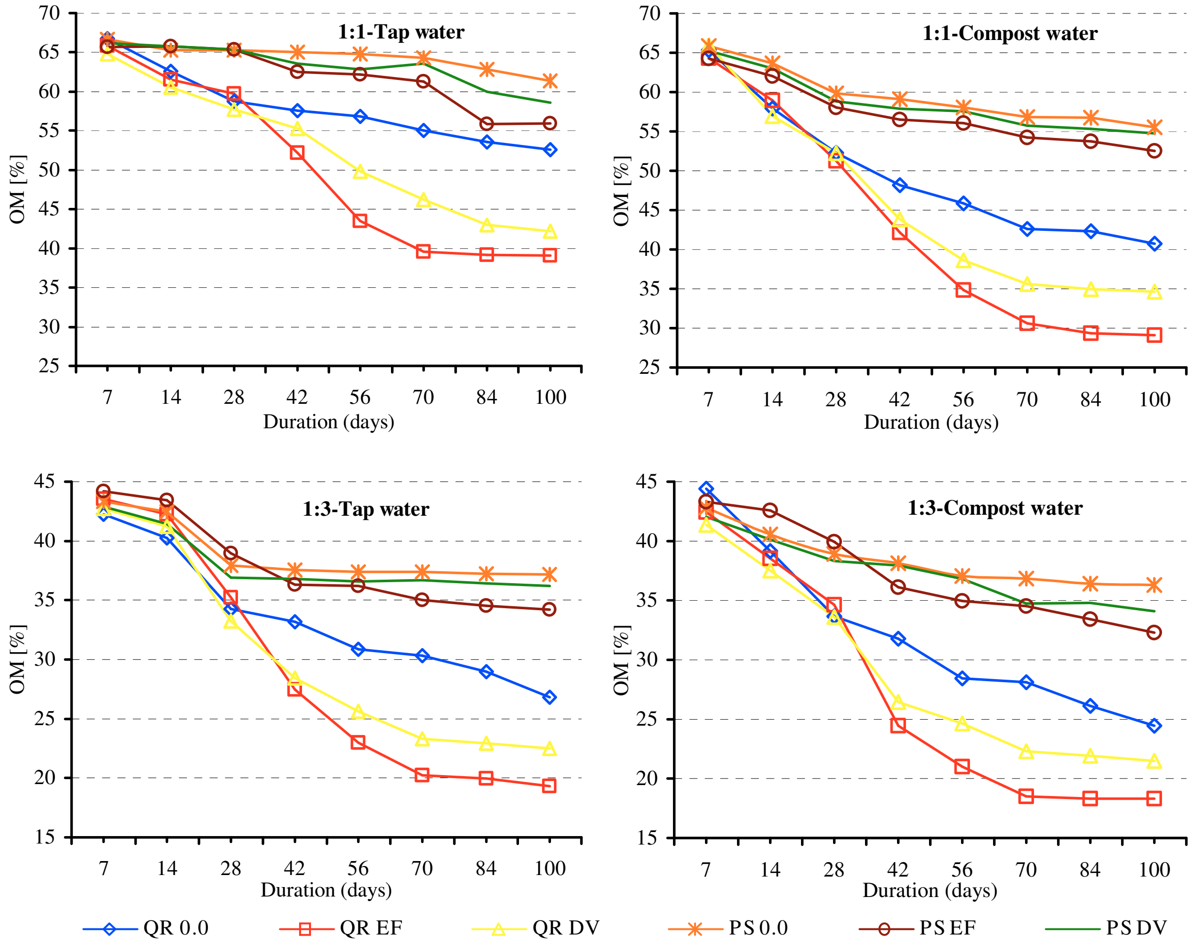


Fig. 4.6: Variation of organic matter content during composting of wood under different studied treatments (data represent averages of three replicates)

Generally, the decreasing rate of OM content of *QR* compost was higher than that of *PS* compost. This may be due to the decomposition rate of *QR* wood compost was higher than that of *PS* wood compost. This trend also was reflected by the OM content at the end of incubation period (100 days), where the *PS* wood treatments are higher in OM content than that in *QR* mixtures (Fig. 4.6). Furthermore, it can suggest the *PS* wood have been more difficult in eating by worms and microorganisms and contain more toxic substances compared with *QR* wood. The degradation and decomposition rates of wood compost moisted by compost water were higher than this in tap water treatments. This trend may be is the reason why the decreasing rate in OM content of compost water treatments was higher than the other of tap water treatments. These results were attributed to the enhanced effect of compost water on the decomposition and humification of woodchips. The positive impact resulted from the high content of nutrients and microorganisms of compost water compared with those presented in tap water (TAKESHI et al., 2004; WANG et al., 2005).

Regarding to the effect of mixed ratio of woodchips and lake mud on the prepared vermicompost content of OM, the data illustrated by Figure 4.6 show that, the content of OM of the studied two mixed ratios can be arranged as 1:1 > 1:3 (wood : LM). This means that, the compost content of OM was increased with increasing amount of woodchips in the mixture. The decreasing rate of OM content in 1:3 mixing ratio was higher than that in 1:1 mixture. This is may be due to the low C:N ratio in 1:3 mixing ratio which increase growth and activity of microorganisms. Reduced nitrogen in the compost materials will negatively impact on the microbial activity. Also, during composting period the content of OM was clearly affected by the used earthworm species. The high content of OM was found in the treatments uninfected by worms, while the lowest values were appear in the *EF* worm treatments. The treatments infected by *DV* worm came with intermediate values of OM. These trends could be explained by *EF* worm increased the mineralization rate of woodchips compared with *DV* worm and control (EDWARDS, 2004; NATHAN, 2004; GAJALAKSHMI et al., 2005; TOGNETTI et al., 2005).

The content [%] of total organic carbon (TOC) of the prepared compost was clear affected by the studied treatments. During the composting process, TOC in all pots sharply decreased in the first 70 days of composting and from 24.0 – 38.7 % initial carbon content, it dropped to nearly 10.6 – 35.6 % at the end of the composting period (Fig. 4.7 and Table A.7). Throughout the composting process, TOC loss in *PS* wood treatments was lower than that of *QR* wood mixtures (EILAND et al., 2001). This trend was similar and related with this compost content of OM. The compost content of TOC was decreased with the increase of incubation period. This trend was found with most treatments under study. The TOC content decreased during composting process due to the mineralization of the OM by microorganisms and earthworms. The reduction of organic carbon shows the earthworms rapidly multiplying and decomposing the organics.

Also, the obtained data show that, the content of TOC in the compost moisted by tap water was higher than that associated the compost water treatments. This decrease in TOC during composting may be resulted from the oxidation of carbon to carbon dioxide by microorganisms during composting process (TIQUIA et al., 2002). As can be seen in Figure 4.7, it is possible to appreciate that the lower TOC content of 1:3 mixing ratio compared to 1:1 (wood : LM) is dependent upon the different composition of the initial blends of raw materials (NATHAN, 2004). The infection treatments by earthworms influenced the compost content of TOC, where the lowest values of TOC was found in the compost infected by *EF* worm, which associated by high rates of wood decomposition and degradation. The earthworms promote such microclimatic conditions in the vermireactor that increase the loss of organic carbon from substrates through microbial respiration. These results are in agreement with the findings of (VINCESLAS-AKPA & LOQUET, 1997; AIRE et al., 2002; MABOETA; RENSBURG, 2003 & SUTHAR, 2006).

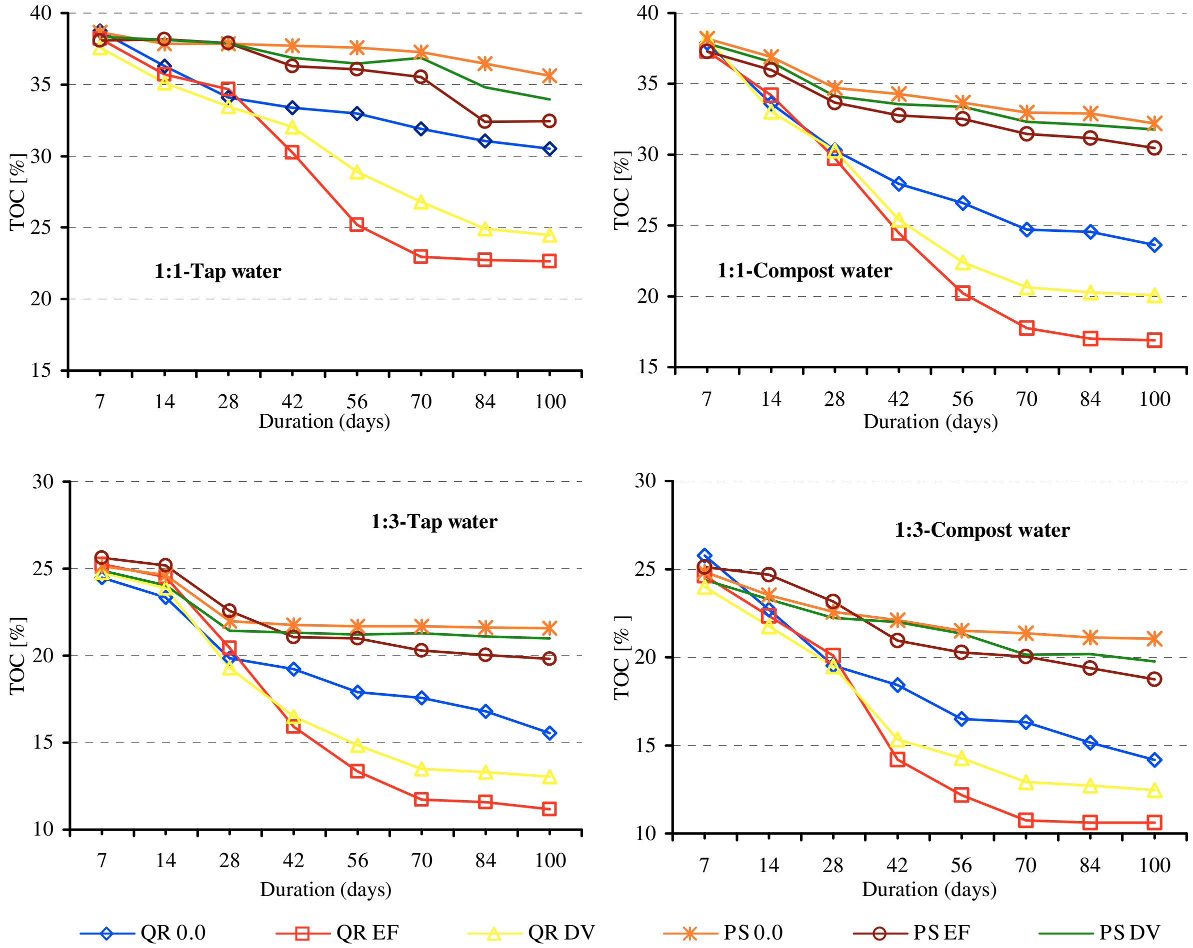


Fig. 4.7: Variation of total organic carbon during composting of wood under different studied treatments (data represent averages of three replicates)

A decline in total extractable carbon is one of the indicators of compost maturity. The effect of the studied treatments on the compost content [%] of total extractable carbon (TEC) was illustrated by Figure 4.8 (Table A.8 in the Appendix). Total extractable C of the compost displayed a similar trend to total organic C. The different treatments confirmed that TEC decreased predominantly during the composting process due to the intense mineralization process. Throughout the composting process the compost content of TEC can be summarized in the following points:

a) The decreasing rate of TEC content in *QR* wood treatments was higher than that in *PS* wood treatments. This is due to high degradation rate of *QR* wood compared with *PS* wood,
b) Compared with OM and TOC, the compost content of TEC was little decreased with the increase of incubation period,
c) The compost moisted by tap water have a high content of TEC compared with that associated the compost water treatments,
d) The arrangement of the tested mixed ratio (wood : mud) according to its effect on compost content of TEC was mixing ratio of 1:1 >1:3, and
e) The arrangement of the infection treatments according to its effect on the compost content of TEC was uninfected compost > compost infected by *DV* worm > compost infected by *EF* worm.

The previous points could be explained by, low decomposition and humification rate of *PS* wood, high effects of compost water of enhancing degradation rate, impact of the initial C:N ratio of the raw materials on microbial activity, and high ability of *EF* worms to eat and digest wood. These results are in agreement with the results obtained by (KAUSHIK & GARG, 2004; WONG et al., 2006).

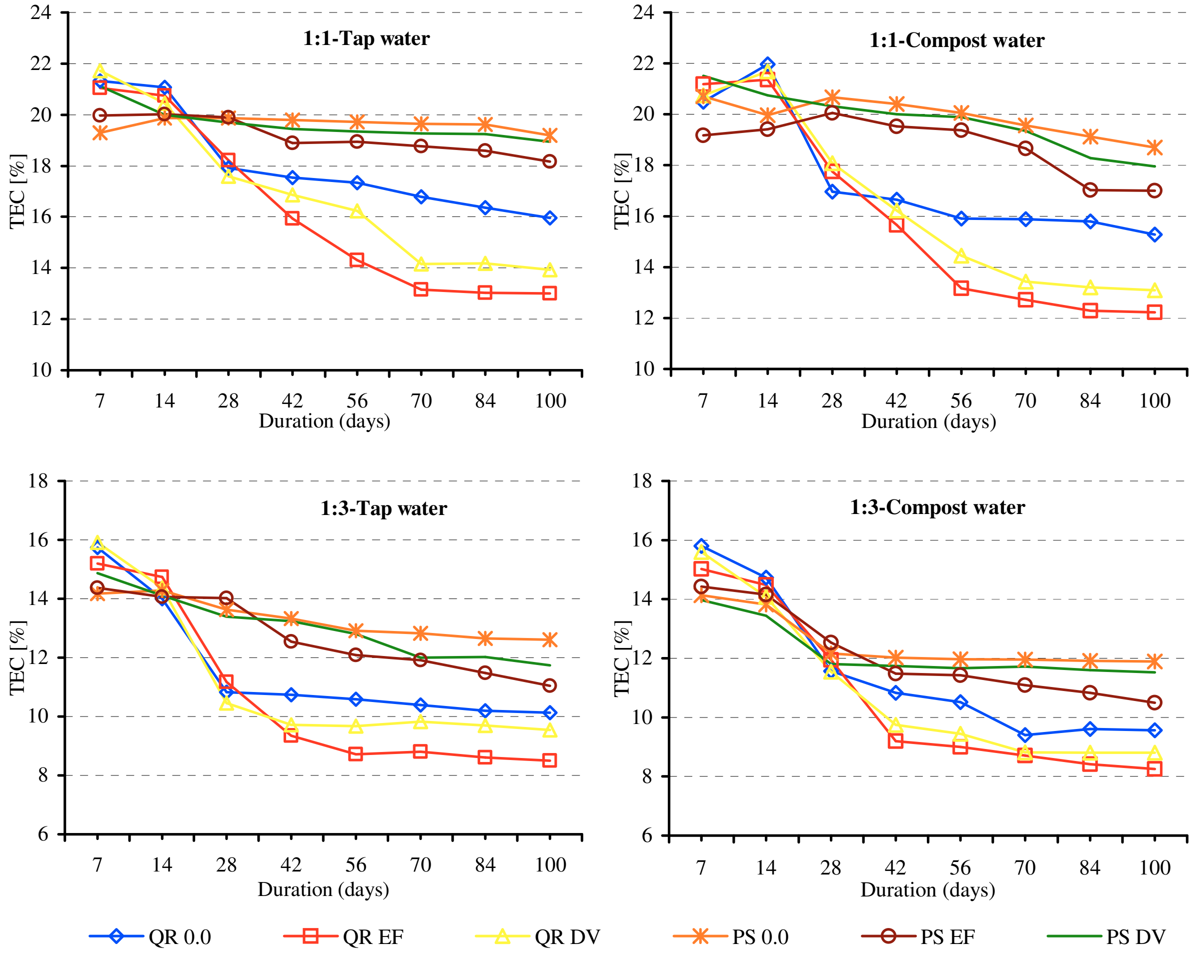


Fig. 4.8: Changes in total extractable carbon during composting of wood under different studied treatments (data represent averages of three replicates)

4.1.1.6. Humic substances and humification parameters

In order to evaluate the maturity level of the organic matter composted through the composting process, humification parameters have been used to discriminate stabilized form. Changes in Humic acids (HA), Fulvic acids (FA), degree of humification (DH), humification rate (HR), and humification index (HI) usually were used to evaluate the compost maturity and stability. The increased level of HA represented the presence of humification process, indicating the maturity of compost. Since the levels of HA normally vary according to the source of raw materials. The humic acid concentration increases and depends upon the nature of the substrate and the composting technique. In general, fresh compost contains obviously lower levels of HA as compared to mature compost, and a small change may occur in FA (CHEFETZ et al., 1998; ADANI & SPAGNOL, 2008). This trend was also observed in our study. The data presented in Tables (A.9 and A.10 in the appendix) and illustrated by Figures (4.9 and 4.10) shows the prepared wood compost content [%] of both humic and fulvic acids (HA, FA) as affected by the studied factors. These data show that, the relationship between the compost content of HA and composting period was a direct relationship in the first period. The rapid increase of HA content was more evident in the first two months and after that it was decreased. While at the last week the HA content increased again. In the same context, data observed that the FA content was increase until the day 70 and after that it was decrease till the end of incubation period. Data also showed the HA content were higher than the FA content of all mixtures during composting period (WONG et al., 2006). These results could be explained by the degradation of organic matter through the composting period.

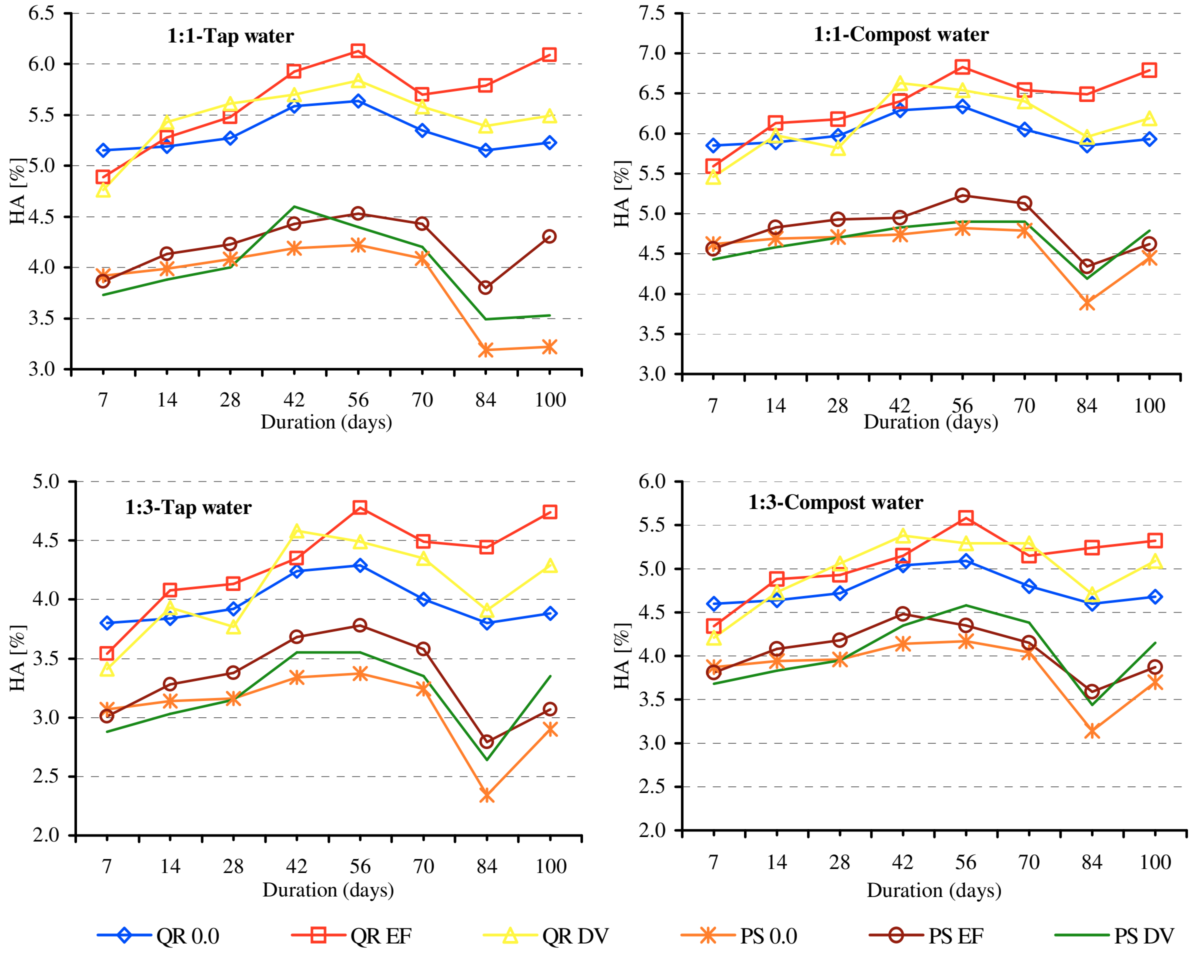


Fig. 4.9: Variation of humic acid content during composting of wood under different studied treatments (data represent averages of three replicates)

It can concluded that, at the beginning of composting time (about 60 to 70 days) the increase of HA and FA content may be reveal to the high content of soluble organic substances and the high activity of microorganisms. In the other side, increase of HA content and decrease FA in the latter period may be due to transformation of FA to create stable compounds of HA or consumption of the FA by microbial activity. These results are in agreement with the findings of (VEEKEN et al., 2000; AIRE et al., 2002; MA & WU, 2002; DESALEGN et al., 2008). Under different studied treatments, the content of either of HA or FA in *QR* compost was higher than that found in *PS* compost. These results may be attributed to the high degradation and humification rate in *QR* woodchips compared with those presented in *PS* woodchips (Tables A.9 and A.10 in the appendix). Also these results may be due to the high amount of HA and FA in *QR* wood compared with those in *PS* wood (Table 3.1).

Also, the analytical data shows the values of both HA and FA in the treatments moisted by compost water was higher than that associated the tap water treatments. This trend may be reveals to the high content of nutrients and microorganisms in compost water compared that found in tap water which affected the decomposition rate. Regarding to the effect of earthworms on wood compost content of HA and FA, the data illustrated by Figures (4.9 and 4.10) showed the high content of either HA or FA was found in the compost infected by *EF* worm, where the lowest content was found in the uninfected compost. This trend reveals to high decomposition rate of woodchips infected by earthworm, especially with *EF* compared to that found with *DV* worm.

These results are in agreement with the results obtained by (VEEKEN et al., 2000; DESALEGN et al., 2008).

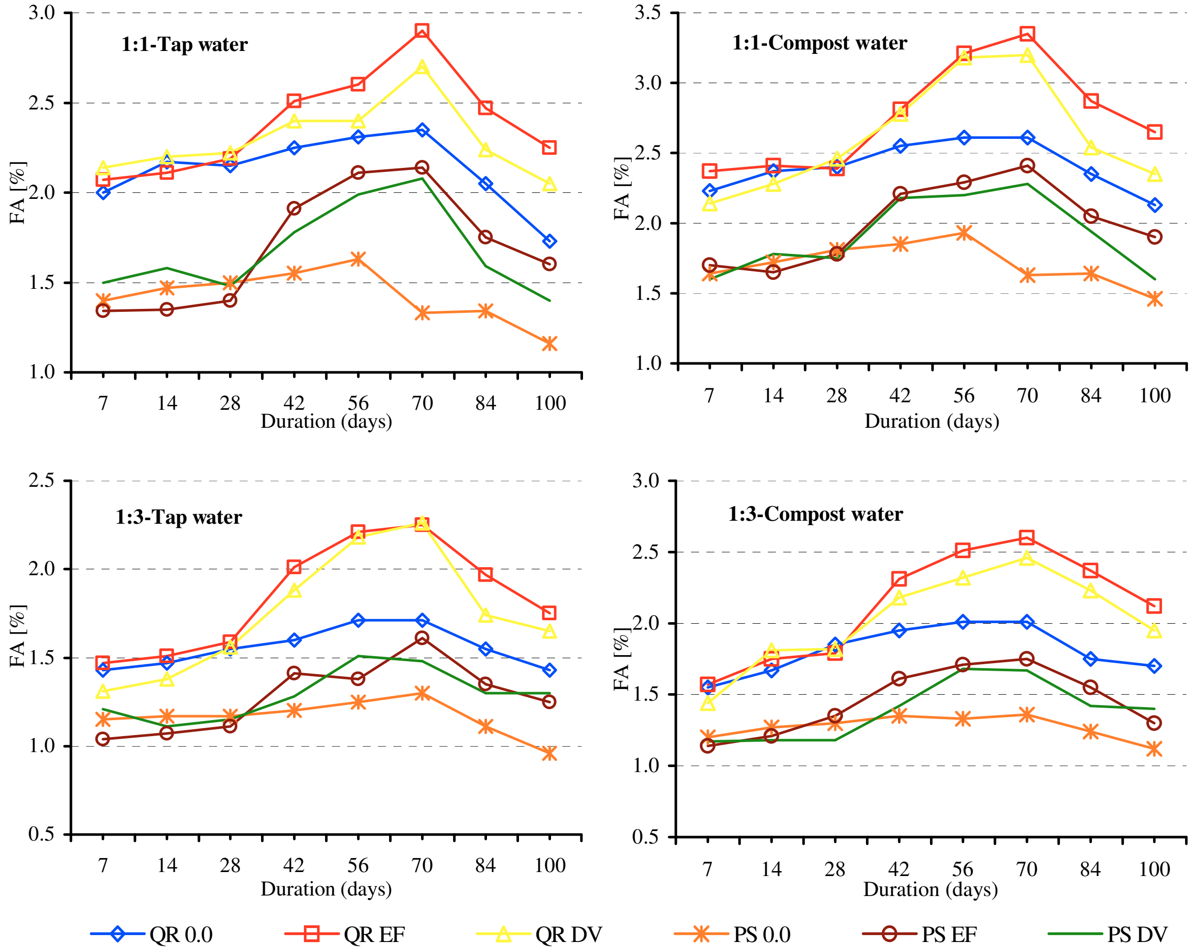


Fig. 4.10: Variation of fulvic acid content during composting of wood under different studied treatments (data represent averages of three replicates)

Finally, the compost content of both HA and FA was clear affected by the studied mixing ratios (wood : LM), where these ratios can be arranged according to their effect on the compost content of both HA and FA as follows: the ratio of 1:1 > 1:3. This trend may be due to the enhancement effect of lake mud on the degradation and decomposition rate of woodchips. Also, this positive effect may be resulted from the high content of nitrogen and other nutrients in lake mud (EILAND et al., 2001; SANCHEZ-MONEDERO et al., 2002; RYNK, 2003). Finally, the highest values (6.8 and 2.8 % at day 56) of HA and FA respectively was recorded to the *QR* wood compost, moisted by compost water, at mixing ratio 1:1 (wood : LM), and infected by *EF* worms. On the contrary, the lowest values (2.9 and 1.0 % at day 100) of HA and FA respectively was recorded for *PS* wood compost, moisted by tap water, at mixing ratio 1:3, and uninfected by worms.

Humifications parameters have been set to evaluate quantitatively the amount of humified carbon produced during the transformation of the organic matter and have demonstrated to assess the stability of compost (CIAVATTA et al., 1993). The calculated values [%] of humification degree (DH) and humification rate (HR) were presented in Tables (A.11 and A.12 in the appendix) and illustrated by Figures (4.11 and 4.12). Throughout the composting process, the values of DH and HR of *QR* wood compost were higher than these of *PS* wood compost. This may be due to high decomposition rate of *QR* wood compared with *PS* wood (BANEGAS et al., 2007). The compost mixture (1*QR*: 3LM + *EF* worms + moisted by compost water) seems to have the highest value of DH and HR at maturity stage (90.5 and 72.2 % respectively). While the lowest values (23.4 and

12.3 %) of DH and HR respectively were recorded for the compost mixture (1*PS* : 1LM + 0.0 worms + moisted by tap water).

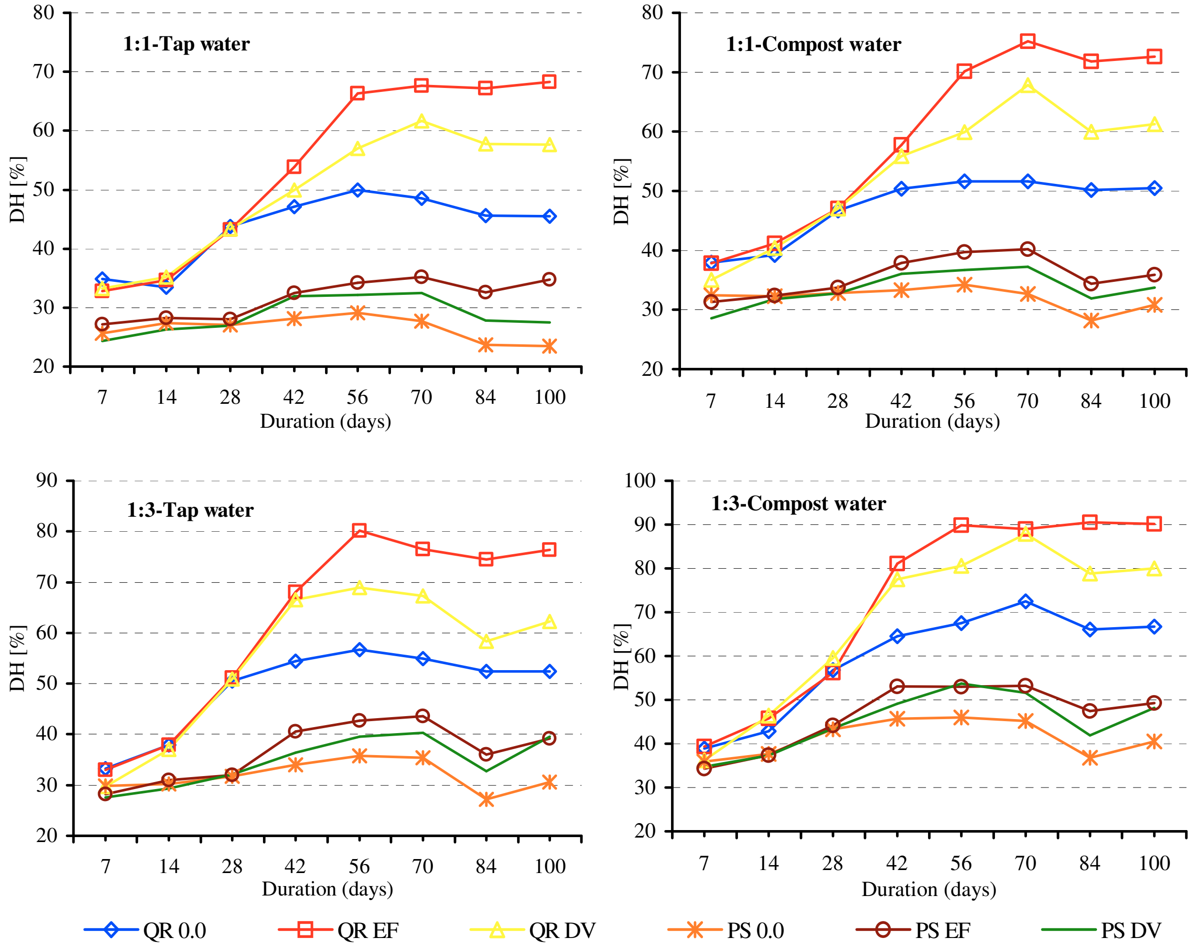


Fig. 4.11: Changes in degree of humification during composting of wood under different studied treatments (data represent averages of three replicates)

Regarding to the effect of incubation period, the values of both DH and HR increased during the first ten weeks and after that it was unsteady till the end of composting. Data also showed the final DH and HR values of all mixtures were higher than the initial values. This could be explained by the degradation and decomposition of wood humic substances during the composting period until the compost entered in the stability stage (CIAVATTA et al., 1993; BERNAL et al., 1998; DESALEGN et al., 2008).

Also, the wood compost moisted by compost water have a high value of DH and HR compared with those found in the compost moisted by tap water. These results were attributed to the enhanced effect of compost water on the decomposition and humification of woodchips. The same data also show that, the highest values of DH and HR were found in the compost infected by *EF* worm, where the lowest values were evident in the compost treatments uninfected by worms. These results are in agreement with the results of (EDWARDS, 1988; KAUSHIK & GARG, 2004; SUTHAR, 2006). The presented data show that, the compost value of both DH and HR was clear affected by the studied mixing ratio (wood : LM). During composting period, the mixing ratio of 1:3 gave the highest values of both DH and HR while the lowest values were recorded to the 1:1 (wood : LM). This trend may be related to the high amount of nitrogen and other nutrients in LM which affected the microbial activity and consequently the degradation of wood.

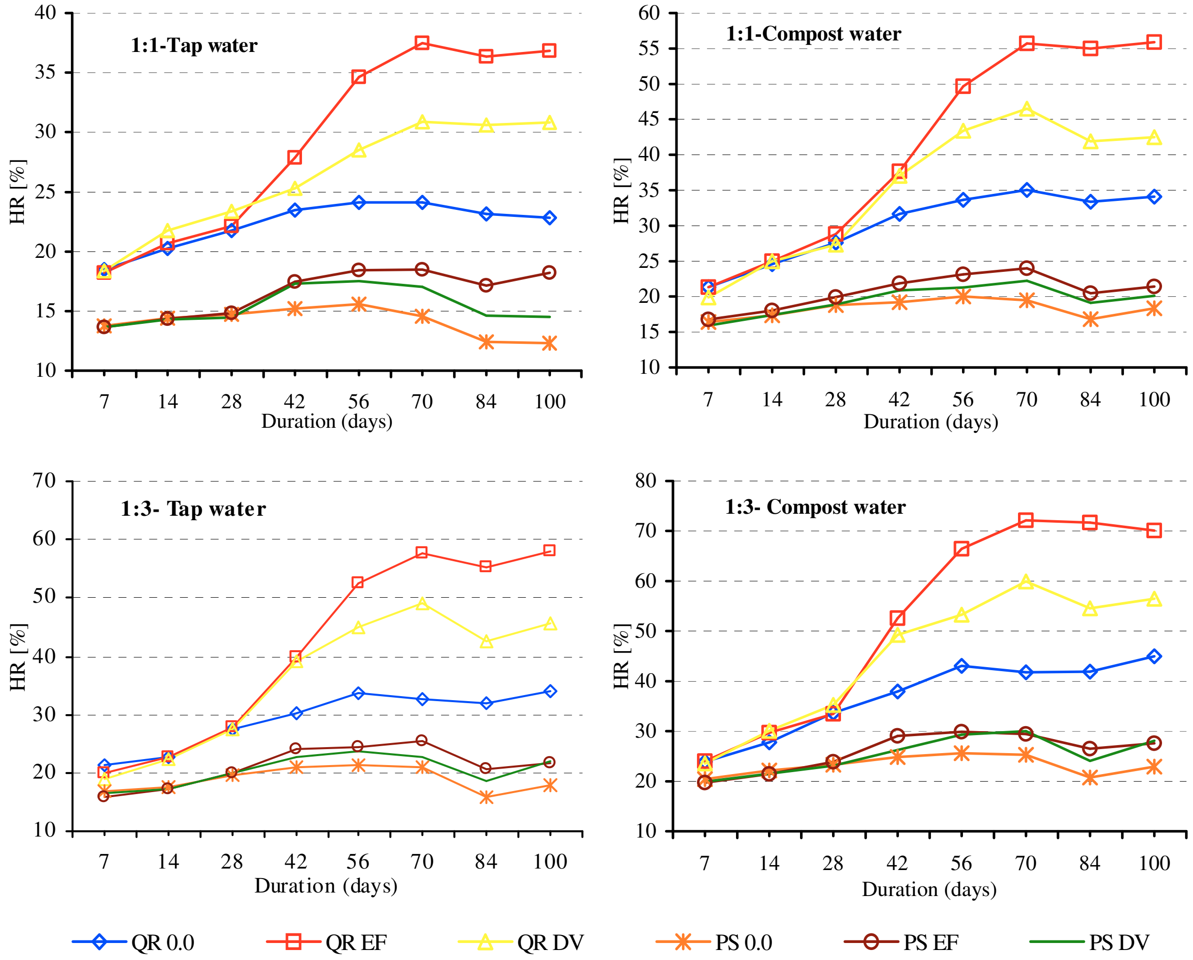


Fig. 4.12: Changes in humification rate during composting of wood under different studied treatments (data represent averages of three replicates)

The calculated values of humification index (HI) of the used woods as a compost material and also as affected by the studied factors were illustrated by Figure 4.13 (Table A.13 in the appendix). These values show that, under different studied treatments the humification index of *QR* compost was lower than that of *PS* compost. This can be concluded that, decomposition rate and degradation of *QR* woodchips were higher than that of *PS* woodchips (Eiland et al., 2001; Takeshi et al., 2004). The relationships between the prepared compost value of HI and the period of incubation was negative (inverse relationship), where this trend was resulted from the increase of decomposition and humification of wood humic substances with the increase of incubation period. The lower HI values used as an indicator of the degree of compost maturity required (Ciavatta et al., 1993; Desalegn et al., 2008). Ciavatta et al. (1990) suggested ≤ 0.5 as the threshold value for the HI parameter in well-stabilized compost. Proceeding from this rule, most of the *QR* wood treatments particularly the treatment infected by *EF* worms are stabilized and all the mixtures of *PS* wood still unstable and immature (Fig. 4.13).

The obtained data show that, the value of HI in the compost moisted by tap water was higher than that associated the compost water treatments. This trend resulted from the high content of OM, microorganisms and nutrients in compost water compared with these presented in tap water. The arrangement of the infected treatments according to its effect on the compost value of HI was uninfected compost > compost infected by *DV* worm > compost infected by *EF* worm (Edwards, 1988; Edwards; 1998; Subler et al., 1998; Edwards, 2004). The value of HI of the studied mixing ratio can be arranged as 1:1 > 1:3 (wood : LM). This means that, value of HI was increased with the increase of woodchips in the compost. Finally, according to Ciavatta et al. (1993) we can concluded that, values of HI changed markedly up to 10 week with decrease and then variations were loss pronounced, indicating a slowing down of the transformation rate, as a function of the decrease of substrate available for biological processes and the increased stability of the organic matter in the compost. Increase value of humification index of *PS* wood compost treatments after the 70 day was due to the high amount of total extractable carbon and low amount of HA and FA. This trend indicated that, *PS* wood compost did not reached to the stable and maturity stage and may be need more time to get to this case. Also this trend reflects the low Humification rat of *PS* wood compost as showed in Figure (4.13). In contrast, HI values of *QR* wood compost under different studied treatments were decreased with the increase of incubation period until the 70 day and after that it was stable. This trend may be due to high susceptibility of *QR* wood to degradation. From the previous dissection it can be concluded that, the determination of humification parameters (HA, FA, DH, HR and HI) could be used to evaluate the quality of wood compost mixtures related to the stabilization level (CIAVATTA et al., 1990; MA & WU, 2002).

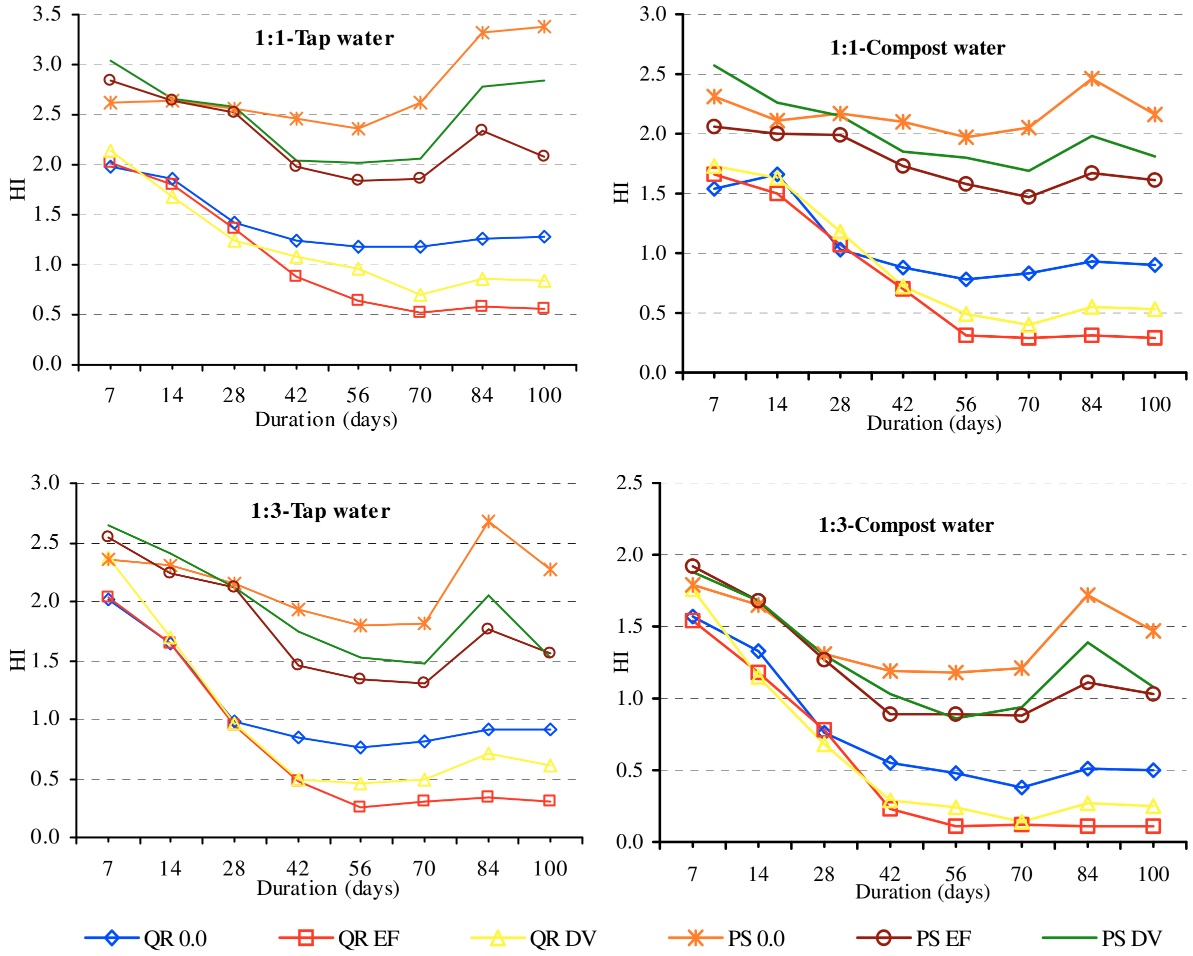


Fig. 4.13: Changes in humification index during composting of wood under different studied treatments (data represent averages of three replicates)

4.1.1.7. Physical and chemical properties of compost

Physical and chemical properties of the final product of wood compost as affected by the studied factors are summarized in Tables 4.1, 4.2, and 4.3. These data reveals that, under all experiment treatments, the compost of *QR* have high values of dry bulk density (BD) compared with that of *PS* compost. This trend may be resulted from the high decomposition rate of *QR* than of *PS*. The other reason may be the high compaction of the first wood compared with *PS* wood. Moreover, bulk density usually increases with composting time as ash content increases and as particle size is reduced by decomposition (RAVIV et al., 1987; NATHAN, 2004). In contrast, the values of water holding capacity (WHC) in *PS* wood compost were higher than those in *QR* wood compost. This could be explained by the high amount of TOC in *PS* compost characterized by a high surface tension which retained more amounts of water (MA & WU, 2002). Also this may be due to high proportion of the non degraded wood in *PS* treatments which absorbed more amount of water.

Electrical conductivity (EC) as an indicator of total soluble salt in *QR* compost was higher than *PS* compost. This reflects the high mineralization rate of *QR* wood compared with *PS* wood (KALE, 1998; MASCIANDARO et al., 1997). The values of pH in *QR* treatments were lower than that in *PS* treatments. The low pH values of *QR* treatments may be resulted from mineralization of nitrogen and phosphorus in to nitrates /nitrites and orthophosphates; bioconversion of organic materials in to intermediate species of organic acids (NDEGWA et al., 2000). Production of CO_2 and organic acid by microbial decomposition during vermicomposting lowers the pH of substrate (SULLIVAN & MILLER, 2001; GARG et al., 2005). The *QR* wood compost contains a low amount of OM, TOC, and TC in comparison with those in *PS* wood compost. This might be caused by easy degradation and mineralization of *QR* wood compared with the difficult degradation and mineralization of *PS* wood. Total nitrogen content (TN) and cation exchange capacity (CEC) in *QR* wood compost were higher than *PS* wood compost. This is due to high mineralization rate of *QR* wood and decreased dry matter. High humic fractions and increasing the fine particles of *QR* treatments can result in increased CEC (ALBANELL et al., 1988; NATHAN, 2004). The C:N ratio gave the normal direction which it depended on the trend of both amount of TC and TN. It was in *QR* wood compost lower than *PS* wood compost, indicated that decomposition was poor in *PS* wood treatments.

Table 4.1: Physical and chemical properties of wood compost as affected by different water types (data represent averages of three replicates)

Parameters / Water type	BD [g cm^{-3}]	WHC [%]	EC [dS m^{-1}]	pH	OM [%]	TOC [%]	CEC [cmol kg^{-1}]	TC [%]	TN [%]	C:N ratio
***QR* wood**										
Tap water	0.62 b	169.71 a	2.45 b	6.73 a	33.32 a	19.55 a	49.12 b	22.17 a	1.37 b	16.18 a
Compost water	0.68 a	138.95 b	5.42 a	6.38 b	27.83 b	16.11 b	52.17 a	18.94 b	1.45 a	13.06 b
LSD $_{0.05}$	0.04	13.63	0.22	0.14	2.58	1.08	1.69	2.81	0.03	2.45
***PS* wood**										
Tap water	0.53 a	214.45 a	1.40 b	7.07 a	46.95 a	27.39 a	46.79 a	28.38 a	1.28 b	22.17 a
Compost water	0.56 a	207.19 a	4.01 a	6.78 b	45.04 a	25.74 a	47.70 a	26.68 b	1.34 a	19.91 a
LSD $_{0.05}$	0.06	12.27	0.19	0.12	2.04	1.77	2.03	1.57	0.04	2.29

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3)

Data in Table (4.1) showed the high significant difference in all studied properties of *QR* wood compost as affected by the two types of water. The high significant values were recorded for tap water treatment in WHC, pH, OM, TOC, TC, and C:N ratio compared with the amount of these properties in compost water treatment. On the other hand, the high significant values were given to compost water treatment in BD, EC, CEC, and TN compared with the amount of these properties in tap water treatment. This trend of the studied properties could be explained by the high mineralization rate of compost water treatment compared with these in tap water treatment. The increase in TN might be due to the activity of nitrogen fixing bacteria which was expected to exist with a high numbers in compost water treatments. These bacteria have the capability to fix N_2 from the air to NO_3 contained in the pots (Huang et al., 2004). There was no significant difference between the values of these properties under different water types in *PS* wood compost (except for EC, pH, TC, and TN). It was indicated that decomposition was poor in *PS* wood treatment as affected by different water types. Data in Table (4.2) showed the high significant differences in all studied properties of *QR* and *PS* wood compost as affected by the used mixing ratios. The values of BD, EC, CEC, and TN in 1:3 were higher than 1:1 mixing ratio. This trend is due to high proportion of lake mud which contains a high amount of these parameters. Moreover this trend may be resulted from the high contents of microorganisms and nutrients in lake mud which increasing the mineralization rate of 1:3 rather than 1:1 mixing ratio. In parallel, the high significant values of WHC, OM, TOC, TC, and C:N was recorded to the ratio of 1:1 (wood : LM). This means the low decomposition and mineralization rate of 1:1 mixing ratio which reflects the high proportion of these parameters. Also, this trend may be due to high residual amount of wood in 1:1 mixed ratio compared with those of 1:3 (wood : LM).

Table 4.2: Physical and chemical properties of wood compost as affected by different mixing ratios (data represent averages of three replicates)

Parameters / Mixing ratio	BD [g cm^{-3}]	WHC [%]	EC [dS m^{-1}]	pH	OM [%]	TOC [%]	CEC [cmol kg^{-1}]	TC [%]	TN [%]	C:N ratio
					***QR* wood**					
1:1	0.51 b	161.23 a	3.68 b	6.40 b	39.13 a	22.84 a	42.67 b	24.09 a	1.38 b	17.46 a
1:3	0.76 a	147.44 b	4.18 a	6.80 a	22.02 b	12.83 b	58.73 a	17.03 b	1.48 a	11.51 b
LSD $_{0.05}$	0.04	10.48	0.18	0.16	1.73	1.60	1.57	1.03	0.05	1.31
					***PS* wood**					
1:1	0.43 b	223.40 a	2.49 b	6.86 b	56.08 a	32.75 a	41.21 b	33.67 a	1.26 b	26.30 a
1:3	0.64 a	198.54 b	2.92 a	6.99 a	34.92 b	20.39 b	53.27 a	21.38 b	1.35 a	15.84 b
LSD $_{0.05}$	0.05	10.68	0.15	0.05	2.21	1.04	1.37	0.89	0.04	1.50

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3)

The clear influence of worms on the degradation rate of wood compost, and therefore on the studied parameters were summarized in Table 4.3. The obtained data showed the high significant effect of *EF* worms compared with *DV* worms and uninfected treatment. In *QR* wood treatments, all the studied properties were significantly affected by the used worms. The high values of BD, EC, CEC, and TN were recorded to the treatment infected by *EF* followed by DV and/or uninfected treatments. The other studied properties of WHC, pH, OM, TOC, TC, C:N ratio characterized with the high values in the control treatment followed by *DV* and finally *EF* worms (Edwards, 1988; Edwards; 1998; Subler et al., 1998; Edwards, 2004). On the other hand, the response of *PS* wood to the infection with worms was observed only between the infected and uninfected treatments (no differences were found between *EF* and *DV* worms). This impact was appeared in the value of pH, OM, TOC, TC, TN, and C:N ratio, while there is no significant effect of the worms on BD, WHC, EC, and CEC values.

The previous trend can be explained by *QR* wood was more response to degrade and decompose by the used worms compared by *PS* wood. This is may be due to the nature and type of wood components. The *EF* worm was more active and influential on the decomposition of wood from the others. The high significant effect of worms on raise or lower the values of the studied properties are due to their positive impact (Especially for *QR* wood treatments) as reported by SINGH et al. (2009). For example, the high value of TN in the worm treatments may be reveals to the addition of nitrogen in the form of mucus, nitrogenous excretory substances, growth stimulating hormones and enzymes from earthworms has also been reported (TRIPATHI & BHARDWAJ, 2004). These nitrogen rich substances were not originally present in feed and might have contributed additional nitrogen content (ALEXANDER, 2001; WARMAN & ANGLOPEZ, 2002).

Table 4.3: Physical and chemical properties of wood compost as affected by different infection worms (data represent averages of three replicates)

Parameters / Worms	BD [g cm^{-3}]	WHC [%]	EC [dS m^{-1}]	pH	OM [%]	TOC [%]	CEC [cmol kg^{-1}]	TC [%]	TN [%]	C:N ratio
					***QR* wood**					
0	0.58 c	162.69 a	3.78 b	6.68 a	35.45 a	20.66 a	48.25 c	23.46 a	1.31 c	17.91 a
EF	0.67 a	145.93 c	4.13 a	6.53 c	26.34 c	15.32 c	55.32 a	18.18 c	1.54 a	11.81 c
DV	0.63 b	154.37 b	3.90 b	6.60 b	29.93 b	17.52 b	51.53 b	20.04 b	1.43 b	14.01 b
LSD $_{0.05}$	0.03	7.25	0.14	0.04	1.68	1.29	1.05	1.39	0.08	1.52
					***PS* wood**					
0	0.55 a	213.17 a	2.67 a	6.97 a	47.36 a	27.56 a	46.71 a	29.06 a	1.27 b	22.88 a
EF	0.59 a	210.05 a	2.82 a	6.89 b	43.45 b	25.54 b	47.93 a	26.26 b	1.36 a	19.31 b
DV	0.57 a	209.69 a	2.73 a	6.92 b	45.69 ab	26.59 ab	47.49 a	27.27 b	1.32 a	20.66 b
LSD $_{0.05}$	0.05	5.35	0.17	0.04	2.32	1.25	1.40	1.13	0.06	1.64

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3)

4.1.1.8. Macro and micro nutrients content of wood compost

Total macro and micro nutrients content of wood compost

The effect of the studied factors on the compost content of total nutrients is recorded in Tables 4.4, 4.5, and 4.6. These data show that, the values of all nutrients in *QR* compost were higher than those in *PS* compost. This trend reflects the high mineralization rate of *QR* wood compared to *PS* wood. The analytical data indicates that the Ca is the predominate cation followed by K, Fe, Mg, P, Mn, Zn, and finally Cu. This rend depends on the amount of these elements in the used raw materials (Table 3.1).

Regarding to the effect of water quality, data in Table 4.4 showed the high significant values of P, Ca, Mg, and K in compost water treatments compared with those in tap water treatments (except Ca in *PS* treatments). The impact of water quality in both woods did not appear any significant differences in the values of micronutrients (Fe, Mn, Zn, and Cu). The high significant effect of compost water on P, Ca, Mg, and K values may be due to his content from these elements. Also the high proportion of microorganism in compost water enhances the mineralization rate and decreased dry matter. Accordingly, decreased dry matter with the same amount of elements is normally the reason of raise these elements (KAUSHIK & GARG, 2004; SINGH et al., 2009). Finally, the enhancement of compost water in the values of studied nutrients may be resulted from chelated these elements from compost water by organic matter (HE et al., 2001).

Total amount of macro and micro nutrients in the final product are clearly affected by the studied mixing ratios (Table 4.5). The compost produced from 1:3 mixed ratio (wood : mud) was contained the high significant values of all elements in both types of wood (except Cu). This trend could be explained by the high quantity of these elements in lake mud compared with their counterpart in the wood (see Table 3.1). Also this trend may be due to the high microbial activity in 1:3 mixed ratio (wood : mud), which lead to increase the mineralization rate (TIQUIA et al., 2002; KAVIRAJ & SHARMA, 2003; WONG et al., 2006).

Table 4.4: Total macro and micro nutrients content of wood compost as affected by different water types (data represent averages of three replicates)

Parameters / Water type	Macronutrients [g kg^{-1}]				Micronutrients [mg kg^{-1}]			
	P	Ca	Mg	K	Fe	Mn	Zn	Cu
				***QR* wood**				
Tap water	0.37 b	11.87 b	1.08 b	4.65 b	5566.46 a	436.15 a	44.56 a	16.33 a
Compost water	0.53 a	13.34 a	1.24 a	6.39 a	5589.72 a	440.63 a	49.22 a	16.38 a
LSD $_{0.05}$	0.02	1.06	0.04	1.36	38.92	9.52	5.24	0.48
				***PS* wood**				
Tap water	0.30 b	11.54 a	1.04 b	4.40 b	5518.45 a	411.59 a	43.77 a	16.40 a
Compost water	0.41 a	12.79 a	1.16 a	6.04 a	5532.50 a	417.64 a	46.37 a	16.36 a
LSD $_{0.05}$	0.03	1.42	0.07	1.47	40.96	21.38	4.53	0.44

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3)

Table 4.5: Total macro and micro nutrients content of wood compost as affected by different mixing ratios (data represent averages of three replicates)

Parameters / Mixing ratio	Macronutrients [g kg^{-1}]				Micronutrients [mg kg^{-1}]			
	P	Ca	Mg	K	Fe	Mn	Zn	Cu
				***QR* wood**				
1:1	0.61 b	10.45 b	0.84 b	4.76 b	5795.76 b	378.64 b	35.58 b	16.40 a
1:3	0.67 a	14.75 a	1.46 a	8.97 a	6362.94 a	498.14 a	55.21 a	16.73 a
LSD $_{0.05}$	0.02	0.95	0.05	0.54	141.06	29.75	1.21	0.43
				***PS* wood**				
1:1	0.44 b	10.13 b	0.81 b	4.63 b	5766.76 b	354.81 b	33.92 b	16.55 a
1:3	0.48 a	14.21 a	1.38 a	8.83 a	6294.29 a	474.22 a	54.66 a	16.81 a
LSD $_{0.05}$	0.02	0.75	0.09	0.53	152.04	26.05	1.33	0.40

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3)

The effects of the used worms (*EF*, *DV*) on the values of tested nutrients are presented in Table 4.6. Generally as data indicate, the worm species did not given any significant effects on the compost content of studied nutrients especially in *PS* wood compost. This may be explained by the physical and chemical composition of *PS* wood did not qualify him for degrades and decomposition by worms. In contrary, the *QR* wood compost infected by *EF* worms was found to differ significantly for the majority of the examined nutrients (except Cu). Nevertheless, there are no significant differences in the values of studied nutrients between the treatments infected by *DV* worms and control treatment. The high values of the studied nutrients were observed in the treatments infected by *EF* worms followed by *DV* worms and control. This may be due to the high ability for *EF* worms to eat and digest the *QR* wood compared with the others. The positive impact of the used worms may be resulted from the earthworm processed waste material contains high concentration of exchangeable nutrients, due to enhanced microbial activity during the vermicomposting process, which consequently enhanced the rate of mineralization. For example, the increase in TP of *QR* wood compost, after worm activity is performed partly by earthworm gut phosphates and further release of TP might be attributed to the P-solubility microorganisms present in warm casts (SUTHAR, 2007; SINGH et al., 2009). Also, the gut processes associated with calcium metabolism are primarily responsible for enhanced content of inorganic Ca content in worm cast (GARG et al., 2006). The similar pattern of calcium enhancement is well documented in available literature (BUCHANAN et al., 1988; SENAPATI, 1993). They suggested that increased inorganic Ca content may be attributed to $CaCO_3$ secretions in the worm gut.

Table 4.6: Total macro and micro nutrients content of wood compost as affected by different infection worms (data represent averages of three replicates)

Parameters / Worms	Macronutrients [g kg^{-1}]				Micronutrients [mg kg^{-1}]			
	P	Ca	Mg	K	Fe	Mn	Zn	Cu
***QR* wood**								
0	0.60 b	12.25 b	1.08 b	6.74 b	5556.26 b	433.49 b	46.50 b	16.33 a
EF	0.69 a	13.96 a	1.26 a	7.23 a	5597.43 a	454.43 a	50.80 a	16.35 a
DV	0.63 b	12.46 b	1.12 b	6.78 b	5569.11 b	439.92 b	47.65 b	16.32 a
LSD $_{0.05}$	0.05	0.60	0.08	0.48	25.28	13.78	0.85	0.16
***PS* wood**								
0	0.46 a	12.03 a	1.06 a	6.71 a	5527.09 a	414.45 a	44.60 a	16.30 a
EF	0.46 a	12.34 a	1.13 a	6.75 a	5533.50 a	423.90 a	44.97 a	16.33 a
DV	0.46 a	12.13 a	1.11 a	6.74 a	5530.83 a	415.69 a	44.81 a	16.36 a
LSD $_{0.05}$	0.02	0.58	0.06	0.37	25.30	22.59	0.77	0.18

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3)

Available macro and micro nutrients content of wood compost

The effects of the studied factors on the compost content of available nutrients are summarized in Tables 4.7, 4.8, and 4.9. The data showed the values of available macro and micro nutrients in *QR* wood compost were higher than those in *PS* wood compost. This trend may be due to high mineralization rat of *QR* wood compost compared to *PS* wood compost. In the final product of both *QR* and *PS* wood compost, the available N content recorded the high value followed by Ca, K, Mg, Fe, Mn, P, Zn, and then Cu. This based on initial chemical composition of raw materials and the extent of decomposition.

The impact of water types on compost available nutrients content found to differ significantly for the *QR* wood compost with the exception of Zn and Cu (Table 4.7). Available studied nutrients of *PS* wood compost was not found significantly different between the two types of water for Ca, Fe, Mn, Zn, and Cu, while a high significant differences observed for N, P, Mg, and K. The high effect of compost water on the compost available nutrients content could be explained by, compost water containing a high proportion of these elements (Table 3.2), which absorbed by compost organic acids and humic substances in available form. Also, the released of available nutrients might be attribute to soluble the nutrients by microorganisms presented in compost water (SINGH et al., 2009). The presented data are supported by the compost EC content which use as indicator for total soluble salts (see Table 4.1) (KALE, 1998; MASCIANDARO et al., 1997). In addition, the pH values of the compost produced from using different water types may be the reason for his variations in the available nutrients content (SULLIVAN & MILLER, 2001).

Table 4.7: Available macro and micro nutrients content of wood compost as affected by different water types (data represent averages of three replicates)

Parameters / Water type	Macronutrients [mg kg^{-1}]					Micronutrients [mg kg^{-1}]			
	N	P	Ca	Mg	K	Fe	Mn	Zn	Cu
***QR* wood**									
Tap water	3626.66 b	32.08 b	2384.23 b	396.40 b	400.56 b	169.79 b	65.42 b	9.83 a	1.15 a
Compost water	3838.44 a	51.72 a	2558.63 a	458.52 a	568.11 a	194.43 a	73.09 a	11.60 a	1.17 a
LSD $_{0.05}$	79.42	11.84	112.25	34.4	88.05	14.55	3.88	2.55	0.04
***PS* wood**									
Tap water	2988.42 b	28.40 b	2308.88 a	374.47 b	397.80 b	164.55 a	61.74 a	8.75 a	1.17 a
Compost water	3147.25 a	38.52 a	2458.17 a	417.60 a	543.60 a	168.28 a	62.65 a	10.93 a	1.15 a
LSD $_{0.05}$	85.38	8.76	184.15	25.08	76.13	12.93	6.11	2.30	0.04

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3)

Data in Table (4.8) showed the high significant difference in all examined nutrients of *QR* and *PS* wood compost as affected by the used mixing ratios (except Cu). The high available values of these nutrients were recorded to the compost produced from 1:3 while the low values observed in the compost obtained from 1:1 mixing ratio. This should be mainly attributed to the different content of nutrients in the input materials. The lake mud tends to appear with a higher values from these nutrients compared to *QR* and *PS* woods (Table 3.1). The other reason may be the high mineralization rate of 1:3 mixing ratio which attributed the solubility of the studied nutrients (BERROW & REAVES, 1984; ALEXANDER, 2001; HE et al., 2001; SULLIVAN & MILLER, 2001).

Table 4.8: Available macro and micro nutrients content of wood compost as affected by different mixing ratios (data represent averages of three replicates)

Parameters / Mixing ratio	Macronutrients [mg kg^{-1}]					Micronutrients [mg kg^{-1}]			
	N	P	Ca	Mg	K	Fe	Mn	Zn	Cu
***QR* wood**									
1:1	3653.14 b	39.98 b	2190.93 b	322.60 b	439.77 b	155.27 b	64.80 b	9.72 b	1.15 a
1:3	3917.86 a	48.04 a	2930.11 a	524.13 a	821.78 a	198.03 a	82.72 a	11.73 a	1.16 a
LSD $_{0.05}$	112.36	1.84	190.13	28.04	123.18	35.44	7.53	1.72	0.04
***PS* wood**									
1:1	2988.42 b	35.76 b	2026.76 b	291.67 b	416.73 b	143.05 b	53.22 b	8.50 b	1.18 a
1:3	3173.72 a	40.36 a	2842.42 a	496.81 a	794.63 a	188.83 a	71.13 a	10.61 a	1.15 a
LSD $_{0.05}$	105.89	0.92	155.73	32.36	126.75	31.27	8.11	1.52	0.04

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3)

The effects of the used worms on the compost available nutrients content are summarized in Table 4.9. The data reveals that under different worm treatments there was no significant diversification in the content of available nutrients for *PS* wood compost. This indicates the *PS* wood is difficult to eat and digest by the used worms. May be the *PS* wood contain a high amount of lignin which led to increase the wood fiber hardness, which consequentially affected the ability of worms to eat it. Also, the *PS* wood may be containing toxic and pungent smell substances which deter the worms of eating them. However most studied nutrients recorded a slightly higher concentrations for the compost infected by *EF* followed by *DV* and control. In contrast, the *QR* wood compost was more responsive to the impact of the used worms, especially for the *EF* worm (Table 4.9). This impact was found with all nutrients with the exception for Zn and Cu. There are a high significant differences among the worm species for the majority of the examined nutrients (particularly for N and P). Besides, there are no significant differences in the values of studied nutrients between the treatments infected by *DV* worms and control treatment for Ca, Mg, K, Fe, and Mn.

The high values of the studied nutrients were observed in the treatments infected by *EF* worms followed by *DV* worms and finally control. This trend reflects the high ability and activity of the *EF* worm for eating and digesting the *QR* wood compared to the others. Comparison with *DV* worm, the *EF* worm enhanced the nutrients mineralization rate due to enhanced microbial activity during the vermicomposting process by his gut microorganisms (SUTHAR, 2007). The other reason may be growth stimulatory hormones and enzymes from the gut of worms (TRIPATHI & BHARDWAJ, 2004). Moreover, increased total macro and micro nutrients and CEC as showed previously might be causes increased available nutrients (GOYAL et al., 2005). For example, available P form is performed partly by earthworm gut phosphatases and further released of phosphorus might be attributing to phosphorus solubilizing micro organism present in worm cast. Similarly as in phosphorus, it would be in the rest of the studied nutrients (SINGH et al., 2009).

Table 4.9: Available macro and micro nutrients content of wood compost as affected by different infection worms (data represent averages of three replicates)

Parameters / Worms	Macronutrients [mg kg^{-1}]					Micronutrients [mg kg^{-1}]			
	N	P	Ca	Mg	K	Fe	Mn	Zn	Cu
***QR* wood**									
0	3467.83 c	38.44 c	2490.16 b	398.80 b	636.61 b	176.09 b	71.02 b	9.60 a	1.15 a
EF	3976.69 a	51.28 a	2597.41 a	445.40 a	671.19 a	203.24 a	80.66 a	9.88 a	1.18 a
DV	3785.50 b	42.95 b	2492.45 b	413.23 b	630.23 b	178.11 b	71.98 b	9.57 a	1.18 a
LSD $_{0.05}$	182.77	2.76	90.73	20.54	23.80	18.35	5.50	2.33	0.04
***PS* wood**									
0	2991.91 a	33.92 a	2406.27 a	381.53 a	607.93 a	165.81 a	62.17 a	8.92 a	1.15 a
EF	3100.19 a	34.47 a	2468.83 a	406.80 a	609.51 a	166.02 a	63.60 a	8.90 a	1.17 a
DV	3034.30 a	34.20 a	2426.74 a	399.61 a	606.64 a	165.92 a	62.35 a	8.95 a	1.15 a
LSD $_{0.05}$	158.84	1.90	116.95	21.13	20.55	15.93	6.43	2.05	0.04

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3)

4.1.1.9. Compost color and odor properties

All the previous results of compost physical and chemical properties are demonstrated by the morphological features of the final product under different studied treatments. The color of organic matters seems to be brown and turns into black at the end of composting process. Figures A.2 and A.3 in the Appendix showed the large differences among *QR* and *PS* wood compost compared to their status at the beginning of experiment (Figure A.1). The best treatments of vermicompost produced from *QR* wood characterized with dark color, homogenous and did not contain any woodchips (Figure 4.14). In contrast, the *PS* wood compost in all treatments appeared with a lighter color, heterogeneous, and contains higher amounts of wood (Figure A.3). The color of *PS* compost did not change compared to his initial case. It means the *QR* wood compost reached to the maturity and stability stage compared to the compost of *PS* wood. Regarding to the color of compost, increase the brightness of black color is a guide to increase the rate of maturity.

On this basis, the *QR* wood treatments could be arranged by their color or maturity as the treatment of (1:3 mixture + *EF* worm + compost water) is more black and mature followed by (1:1 mixture +*EF* worm + compost water), (1:3 mixture +*EF* worm + tap water), and finally (1:1 mixture + *EF* worm + tap water). Also, there are no offensive odors in the mature *QR* vermicompost compared to the high odors produced from the immature *PS* wood compost (DRUILHE et al., 2002). This trend may be due to the worms in *QR* compost improved aeration, increased aerobic microbial activity, and limiting malodorous anaerobic activity (TIQUIA et al., 2002). The high malodorous in *PS* compost treatments may be due to, the inactive worms (more of it are died) which lead to the absence of tunnel and hence the supremacy of anaerobic populations. Anaerobic microbial populations surpass aerobic species. As a result, malodorous fatty acids and methane levels may increase (DRUILHE et al., 2002; NATHN, 2004).

1WC:3LM+EF 1WC:1LM+EF

A. Tap water treatments

1WC:3LM+EF 1WC:1LM+EF

B. Compost water treatments

Fig. 4.14: The best treatments of the successful wood compost (*QR*)

The high differences appeared on the first compost experiment between the studied treatments will take us to use the successful wood and worm in more big experiment (40L pot). It is clear the best wood and worm are *QR* wood and *EF* worm respectively. The best wood and worm were used in the second compost experiment which will be explained in following section.

4.1.2. Second compost experiment

4.1.2.1. Changes in temperature degree during composting period

Temperature is a mirror, which is the reflection of metabolism of microorganisms in composting mixtures, and also affects the metabolism of microorganisms and the process of composting. The data presented in Figure 4.15 (Table A.14) showed the changes of temperature of wood compost (*QR*) under different studied factors. The initial mean temperature of all treatments was approximately 25.0° C. In all studied treatments the temperature was increased until the day 18 and then gradually dropped till the day 37. From the day 37 until the end of experiment the temperature was oscillated between 20 and 36° C. Generally the level of temperature in the compost mixtures increased and reached to 46.2-54.7° C due to the energy released from biochemical reaction of microorganisms in the compost, while the temperature in compost pots tend to decrease after the thermophilic phase due to the loss of substrate and a decrease in microbial activity. Also, increase temperature at the beginning may be due to high available carbon content which it provides a favorable condition for the growth and biological activity of microorganisms (NDEGWA & THOMPSON, 2000).

Throughout the composting process, temperature degree of 1WC:2HM mixture was the highest followed by 1WC:1LM:1HM and then 1WC:2LM mixing ratio. It means the decomposition and humification rates of HM treatments were higher than those of LM treatments. This may be due to the HM is a source of N, P, K, easily available C compounds, microbes and neutralizing compounds that enable effective growth of the microbes responsible for OM decomposition and consequent rise in temperature (VEIJALAINEN et al., 2005, 2007; DESALEGN et al., 2008). The good aeration in HM treatments may be the reason of increasing microbial activity. The LM treatments were more compacted, which may cause the lake of oxygen and thus retard microbial activity (VEIJALAINEN et al., 2005). For example, a high temperature of 54.7° C was found in 1WC:2HM mixture at day 18. High temperature continued to be observed in this treatment for about 3 days and then gradually dropped to 25.5 and 33.4° C at day 37 for tap and compost water treatments respectively. After day 37, the temperature varied within a narrow range until the end of experiment (100 days). Other mixing ratios took the same direction, but at a lower rates of thermal changes.

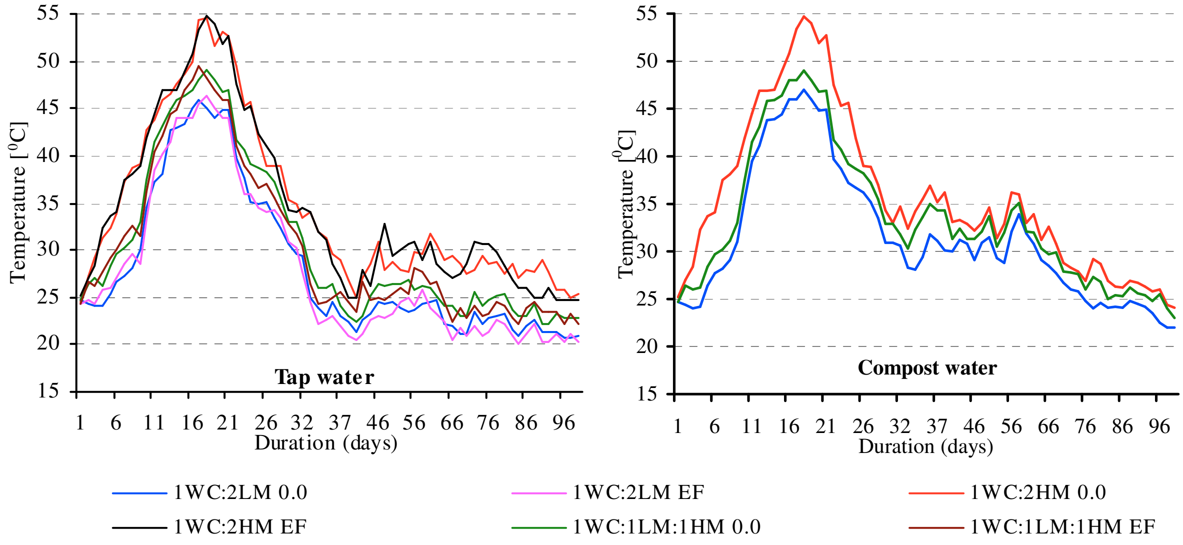


Fig. 4.15: Changes in temperature degree during composting of *QR* wood under different studied treatments (data represent averages of three replicates)

During the first month the treatments in each mixing ratio are considered as a single treatment, because they are all irrigated by compost water, therefore between them no differences of temperature. After the first month the temperature in the treatments of each mixing ratio were unsteady. The application of tap water after 30 days for the *EF* worm and uninfected treatments did not give any differences in temperature compared with the other continued irrigate with compost water and uninfected with worms. This may be due to the worms added after compost entered in mesophilic phase and tap water contain very low amount of nutrients and may be did not contain any microorganisms (TAJBAKHSH et al., 2008). There is a slight increase in temperature (from 37th to 60th day) of the treatments continued irrigate with compost water compared to the other irrigated by tap water. This could be explained by the high amount of microorganisms and nutrients in compost water. The thermal stability in most studied wood treatments after 60 days means low microbial activity resulted from high amount of non soluble carbon substances like lignin (EILAND et al. 2001).

4.1.2.2. Changes in cumulative carbon dioxide during composting period

The amount of CO_2 [g kg^{-1}] generated during composting process which using as an indicator of microbial respiration rate was presented in Figure 4.16 (Table A.15). The data indicates that, the weekly cumulative amount of CO_2 was increased with the increase of decomposition period up to the third week and gradually dropped after that until the day 91, which it was stable after that till the end of experiment (100 days). The steady increase of the produced CO_2 during the first three week may be resulted from the high amount of soluble carbon, which increases humification and mineralization rates. After three weeks the available carbon decreased and therefore the microbial activity reduced. Specifically, the microbial metabolism of readily soluble carbon (sugars, carbohydrates, and hemicellulose) in the compost feedstock increases, more oxygen is consumed and carbon dioxide released. Once labile C is degraded, microbial activity slows and CO_2 decreased; the majority of the remaining carbon is in the form of lignin (EILAND et al. 2001; DRUILHE et al., 2002; ADANI et al., 2004; DIMITRIS & ROBERT, 2006).

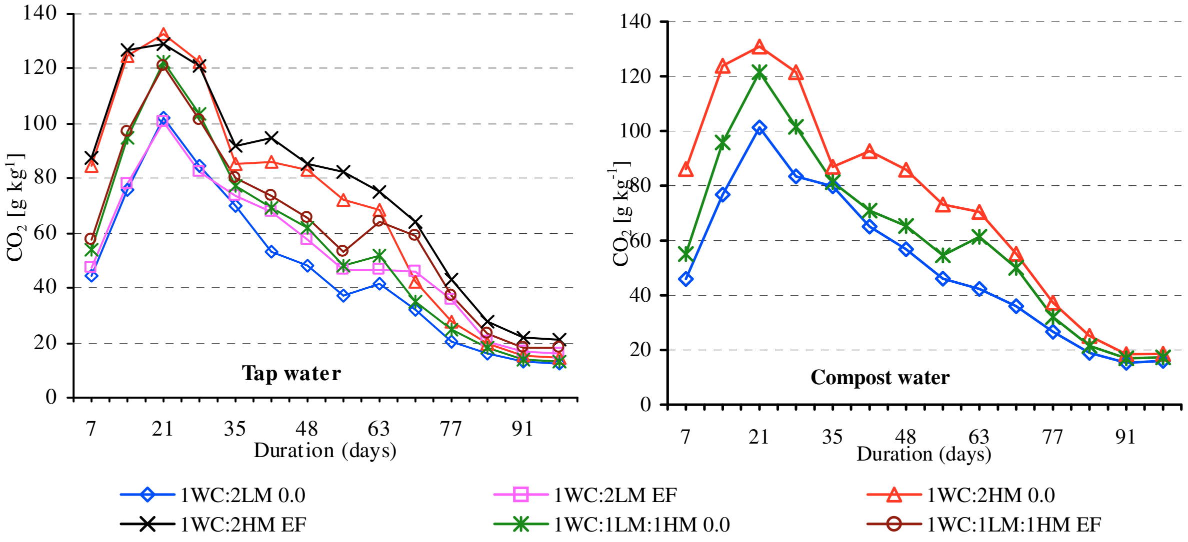


Fig. 4.16: Changes in weakly cumulative amount of CO_2 produced from composting of wood under different studied treatments (data represent averages of three replicates)

Also, the values of CO_2 presented in Figure 4.16 showed the high differences among different mixing ratios. Throughout the composting process, the high values of CO_2 recorded to the mixture of 1WC:2HM followed by 1WC:1LM:1HM and finally 1WC:2LM mixture. This trend may be resulted from the high content of soluble carbon and microorganisms of HM compared with these of LM, where these components enhanced microbial activity, and consequently enhanced mineralization rate of wood (TIQUIA, 2005; VEIJALAINEN et al., 2005; DIMITRIS & ROBERT, 2006; DESALEGN et al., 2008). The produced CO_2 during composting of wood is clearly affected by the studied treatments in each mixing ratio, particularly after passage one month of the experiment. During the first month, there are no differences in the amount of CO_2 were found between different studied treatments. After the first month and until the end of experiment, the high amount of CO_2 was observed in the *EF* worm treatment followed by the treatment continued irrigate with compost water and finally the other irrigated with tap water and uninfected by worms. This trend means the *EF* worm and compost water enhanced mineralization rate by their high effect on microbial activity. Earthworms modify the substrate condition which consequently promotes the carbon losses from the substrate through microbial respiration in form of CO_2 and even through mineralization of organic matter (KAVIRAJ & SHARMA, 2003; GARG et al., 2005). The high content of microorganisms and nutrients in compost water may be the reason of his positive impact (ADANI et al., 2003; NATHAN, 2004)

4.1.2.3. The quantities of CO_2 produced from composting and burning wood

The cumulative amount of CO_2 producing during composting periods (100 days) and the amount of CO_2 evolved by combustion of wood are presented in Figure 4.17 (Table A.17). It can be noticed that, the cumulative amount of composting CO_2 was lower than combustion CO_2. The amount of combustion CO_2 of *QR* wood was 1860.8 [g kg^{-1}]. The high amount of composting CO_2 was in favor to HM treatments at mixing ratio of 1WC:2HM and infected by *EF* worm (1071.8 [g kg^{-1}]). However the lowest values was emerged in LM treatment at mixing ratio of 1WC:2LM, irrigated with tap water after passage one month, and uninfected with worms (652.0 [g kg^{-1}]). This trend reflects the decomposition processes associated with these treatments. At the end of composting period, the cumulative amount of CO_2 produced from different studied mixtures can be arranged as 1WC:2HM > 1WC:1LM:1HM > 1WC:2LM. In each mixing ratio the high amount of the cumulative CO_2 was recorded to *EF* worm treatments followed by the treatments continued irrigate with compost water and finally the other irrigated with tap water and uninfected with worms. It can be concluded that, composting of *QR* wood reduces the amount of CO_2 emitted from it by burning (ABRIGO, 2008; INGA & ZENONAS, 2008).

On the other side it should be calculate the participated of wood in producing CO_2 during composting, because the composting CO_2 did not come only from the wood, but resulted from both organic carbon (OC) of the wood, HM and LM. As shown in first compost experiment, the amount of CO_2 produced from wood can be calculate based on the amount of OC in both *QR* wood, HM and LM (Table 3.1). The difference between CO_2 produced from degradation organic carbon of wood only and the other amount of CO_2 evolved from burning wood is the stored CO_2 in compost (Fig. 4.18). The calculation is dependent on assumed that, the equal impact of microbial activity on organic carbon degradation for both wood, HM and LM. For example, the average of cumulative amount of CO_2 produced from 100 g *QR* wood in 1WC:2HM + *EF* mixed ratio and irrigated by tap water is 132.61 g. This quantity of CO_2 formed about 71.27 %(1) from the amount of CO_2 evolved by burning 100 g wood (Fig. 4.18-b). So that the stored CO_2 in compost instead of emission to atmosphere is 28.73 % (100 – 71.27) as shown in Figure 4.18-(b) of 1WC:2HM mixed ratio. The relative percentage of cumulative amount of CO_2 produced during composting and the residual percentage of CO_2 which storage in compost are showed in Figure 4.18. Generally, the high percentage of stored CO_2 was recorded to the mixture of 1WC:1LM:1HM followed by 1WC:2HM and finally 1WC:2LM. Although the mixture of 1WC:2HM produced the highest amount of CO_2, but most of this amount comes from the soluble OC in HM. Microorganisms are preferred to start degrading the available carbon in horse manure and then moving towards the hard decomposition OC in wood. Therefore, this is the reason for the low percentage of stored CO_2 in the mixture of 1WC:2LM, no horse manure was found in this treatment and microorganisms were compelled to degrade the OC in wood. Therefore the participation percentage of wood composting in this mixture to reducing the CO_2 emitted by burning was the lowest. In each mixing ratio the studied treatments observed different values of the stored CO_2. The stored amount of CO_2 takes an opposite values of the CO_2 produced by composting. The high percentage of the stored CO_2 was observed in the treatment irrigated with tap water after the first month and uninfected by worms (Fig.4.18-a). Contrary, the low percentage

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(1) = ([132.61 / 186.08] x 100)

of stored CO_2 was recorded to the treatment infected by *EF* worm (Fig. 4.18-b). This trend indicates the treatments characterized with low humification rate produced the low amount of CO_2 and consequently stored high amount of CO_2.

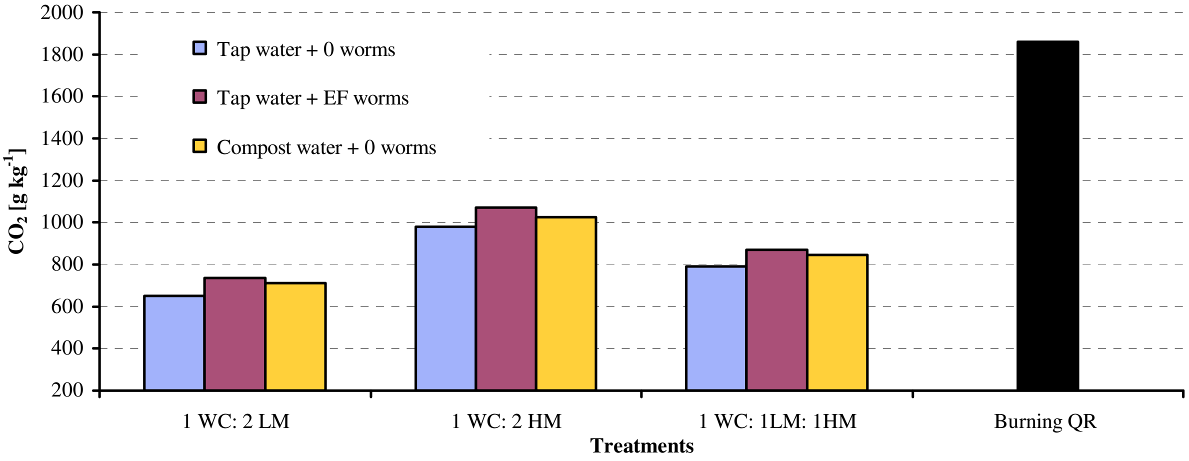
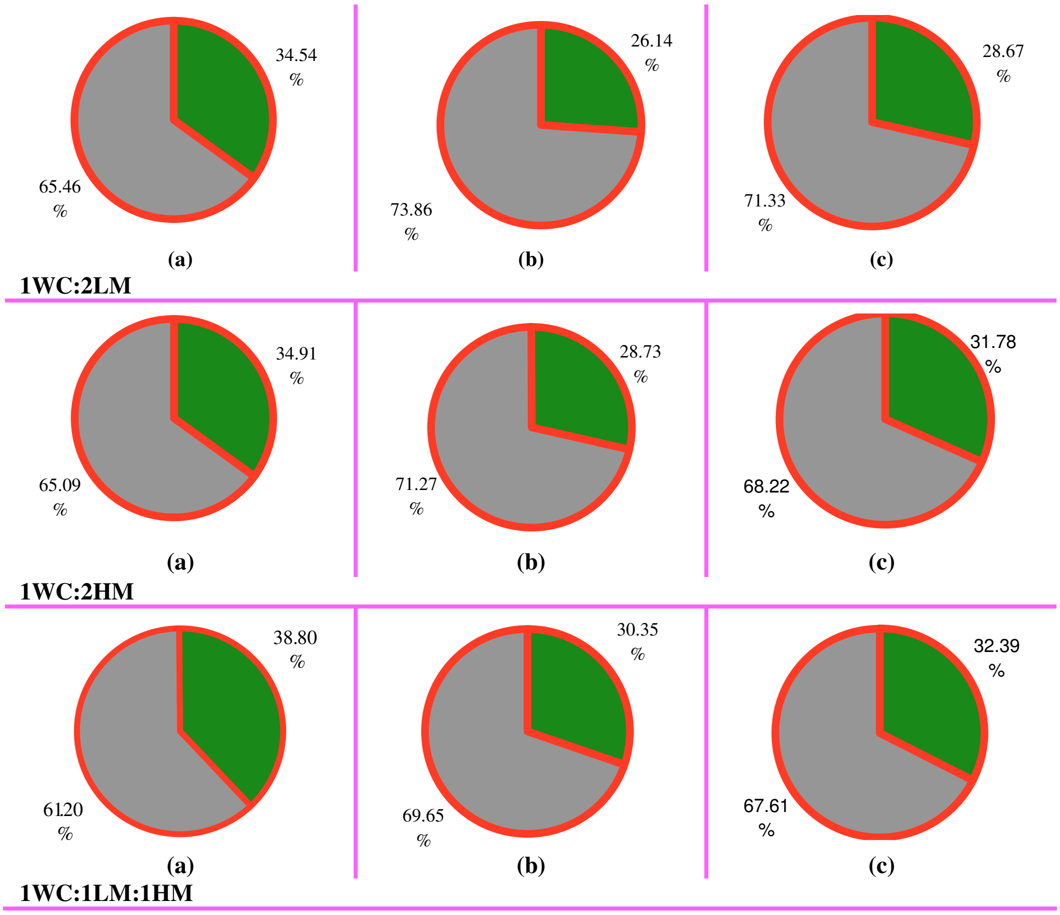


Fig. 4.17: Cumulative amount of CO_2 during composting period and the other CO_2 evolved by burning *QR* wood



🟩 Amount of the residual CO_2 in compost as a percentage [%] of total CO_2 evolved by burning.

⬜ The cumulative amount of CO_2 produced during composting as a percentage [%] of total CO_2 evolved by burning.

○ 100 % CO_2 evolved by burning wood.

(a): Tap water + 0.0 worms **(b):** Tap water + *EF* worms **(c):** Compost water + 0.0 worms

Fig. 4.18: Relative percentage of the Cumulative CO_2 produced during composting period and the residual CO_2 storage in compost to CO_2 evolved by burning *QR* wood

4.1.2.4. Degree of biodegradation

Biodegradation takes place when microorganisms utilize carbon substrates to extract chemical energy that drives their life process. The carbon substrates become food which microorganisms use to sustain themselves. Thus, microbial assimilation/utilization of the substrate carbon as measured by the evolved CO_2 is a measure of biodegradability. Therefore, biodegradation test under controlled compost conditions can be used to study the behavior of microorganisms during composting of wood. Moreover, the value of Biodegradation degree (DB) can be used as a indicator of Susceptibility of wood to decomposition. The DB of *QR* wood compost was calculated depending on the theoretical amount of CO_2 and cumulative amount of CO_2 produced during composting period (Tables A.16 and A.17 in the Appendix). The calculated values of biodegradation degree (DB, [%]) of wood compost as affected by the studied factors were illustrated by Figure 4.19 (Table A.18). These values showed the DB ware increased with the increase of incubation period, particularly at the first period of experiment. This is due to increased amount of CO_2 accumulated and the invariance of theoretical CO_2 (Eq. 3.6). This increase is very small after the day 70 where it means the compost entered in stability phase. This trend also could be related to the high amount of easily soluble carbon in the first period of composting compared with their counterparts at the end of the experiment, which affected the biological activity (NDEGWA & THOMPSON, 2000; TUOMELA et al., 2000; TIQUIA, 2005).

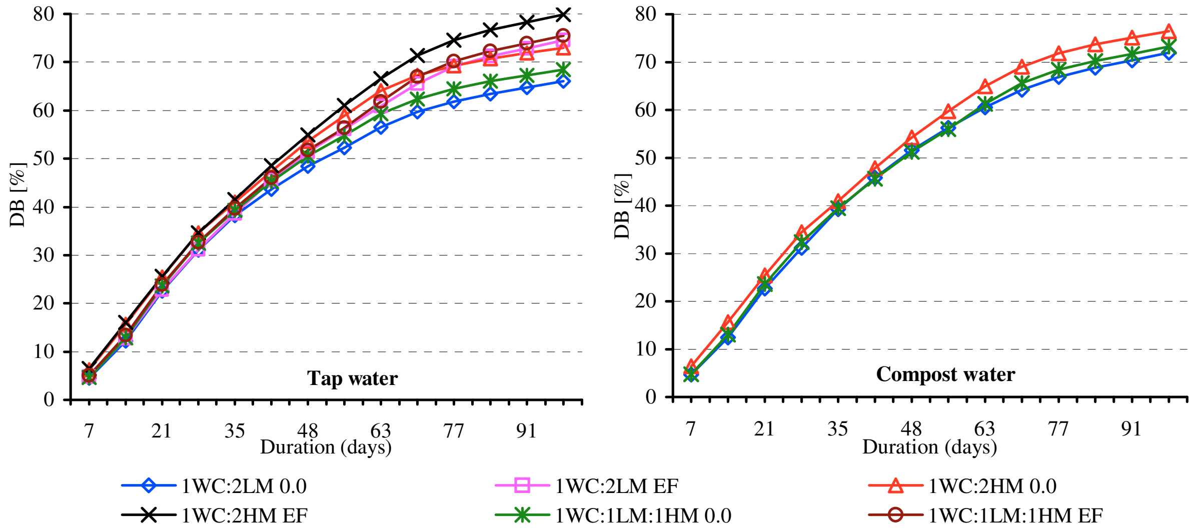


Fig. 4.19: Changes in degree of biodegradation during composting of wood under different studied treatments (data represent averages of three replicates)

Throughout the composting process, the high values of DB observed in the mixture of wood and HM, while the low values recorded to the wood and LM mixture. The horse manure contain high amount of nutrients and microorganisms in comparison with their counterpart in lake mud. This is indicates the horse manure enhanced microbial activity and biodegradation rate (VEIJALAINEN et al., 2005, 2007). Also, the high values of DB were appearing to 1WC:2HM mixture followed by 1WC:1LM:1HM and finally 1WC:2LM mixing ratio. The treatments within each mixture gave the same direction that founded in composting CO_2. The DB value can be arranged as the *EF* worm treatment is the higher followed by the treatment continued irrigate with compost water and finally the other irrigated with tap water and uninfected by worms. This trend indicates the *EF* worms enhanced the break and digest the wood and consequent increases decomposition rate (SINGH & SHARMA, 2003; KAUSHIK & GARG, 2004).

4.1.2.5. Organic matter, total organic carbon and total extractable carbon

Organic matter content of different compost treatments can be seen in Figure 4.20 (Table A.19). The relative decrease of the OM content [%] through the degradation of the compost materials were varied widely as affected by the tested factors. The relationships between the prepared compost content of OM and the incubation period was negative. This trend resulted from the increase of decomposition and degradation of wood organic matter with the increase of incubation period (NATHAN, 2004; ZHANG & HE, 2006; ROU, 2007; LECONTE et al., 2009). The initial values of OM were 47.90, 72.90, and 59.00 % for the mixture of 1WC:2LM, 1WC:2HM and 1WC:1LM:1HM respectively. This trend reflects the high proportion of OM in horse manure. Generally, the decreasing rate of OM content of the wood treated with HM was higher than that of wood mixed with LM. This could be explained by the HM enhanced the microbial activity and accordingly increasing mineralization rate of wood. Also, this may be due to the HM contain high amount of N, P and microorganisms which accelerated the mineralization of wood. During the first month of composting no differences were found among the studied treatments within each mixing ratio. After one month and until the end of experiment there are high variations between these treatments. In each mixing ratio, the lowest values of OM was observed in the *EF* worm treatment followed by the treatment continued irrigate with compost water and finally the treatment moisted by tap water and uninfected by worms. OM contents of the final product based on the initial OM in different mixing ratios. The low OM content recorded to the mixture of 1WC:2LM followed by 1WC:1LM:1HM and 1WC:2HM came belated. The lowest OM value of 1WC:2LM treatments was for the treatment infected by *EF* worm (30.50 %), while the highest OM content was observed in the mixture of 1WC:2HM within the treatment moisted by tap water and uninfected by worms (47.40 %).

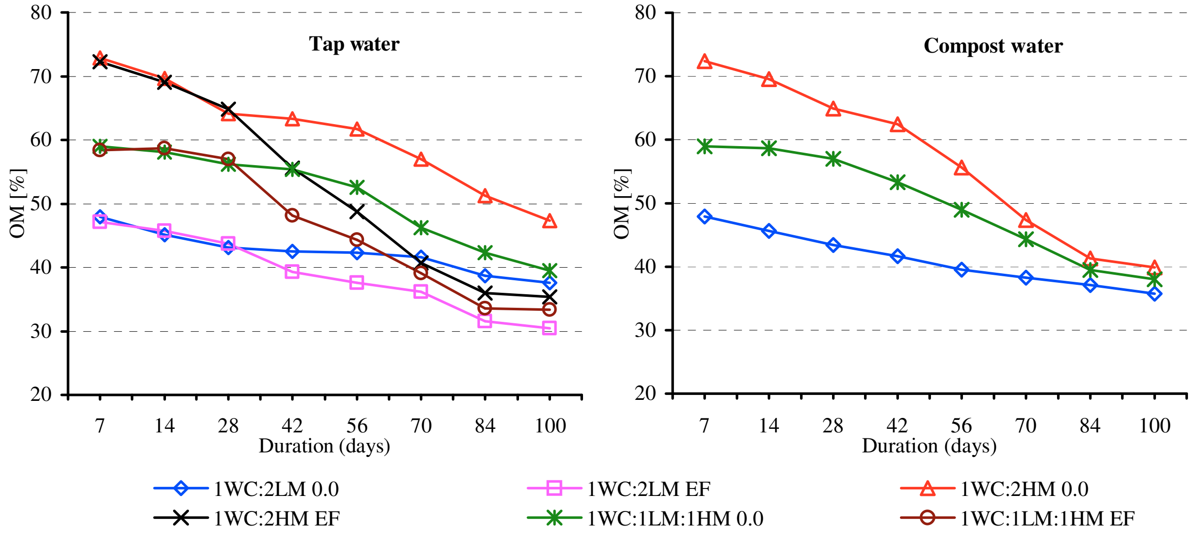


Fig. 4.20: Variation of organic matter content during composting of wood under different studied treatments (data represent averages of three replicates)

This trend means the *EF* worm and compost water microorganisms enhanced mineralization rate by their high effect on microbial activity. Earthworms digest the compost materials which consequently promotes the carbon losses from the substrate through microbial respiration in the form of CO_2 and even through mineralization of organic matter (EDWARDS, 2004; NATHAN, 2004; GAJALAKSHMI et al., 2005; GARG et al., 2005; TOGNETTI et al., 2005, DESALEGN et al., 2008).

Also, the content [%] of total organic carbon (TOC) of the prepared compost was clear affected by the studied treatments. During the composting process, TOC in all pots gradually decreased and from approximately 27.80 – 40.30 % initial carbon content, it dropped to nearly 17.70 – 27.50 % at the end of the composting period (Fig.4.21 and Table A.20). Generally, decreasing rate was very high until the 70th day and after that it was reduce. This might be caused by easy-to-degradation TOC decomposition in the initial 70 days. However, difficult-to-degradation TOC, such as lignin, would be gradually decomposed in curing phase. In the first period the microorganisms prefer to decompose the soluble carbon (carbohydrates and hemicelluloses) while it is obliged to degrade the insoluble carbon (lignin) in the final stages. The differences in TOC of composts at zero time are due to the source of organic materials and the mixing ratio between these materials. Throughout the composting process, decline rate of TOC in the wood mixed by HM treatments was higher than those of the wood mixed with LM. The HM enhanced the activity of worms and microbes and consequently mineralization rate (VEIJALAINEN et al., 2007; DESALEGN et al., 2008). This trend was similar and related to the compost content of OM, it was found with most treatments under study. The TOC content decreased during composting process due to the mineralization of the OM by microorganisms and earthworms. Also, the obtained data show that, the content of TOC in the compost moisted by tap water (without worms) was higher than that associated the treatments continued irrigated by compost water. As can be seen in Figure 4.21, it is possible to appreciate that the lower TOC content of 1WC:2LM mixing ratio compared to the others mixtures dependent upon the different composition of the initial blends of raw materials (NATHAN, 2004). Under different mixing ratios and during composting period the high decreasing rate of TOC was found in the *EF* worm treatment followed by the treatment continued moisted by compost water and finally the uninfected tap water treatment.

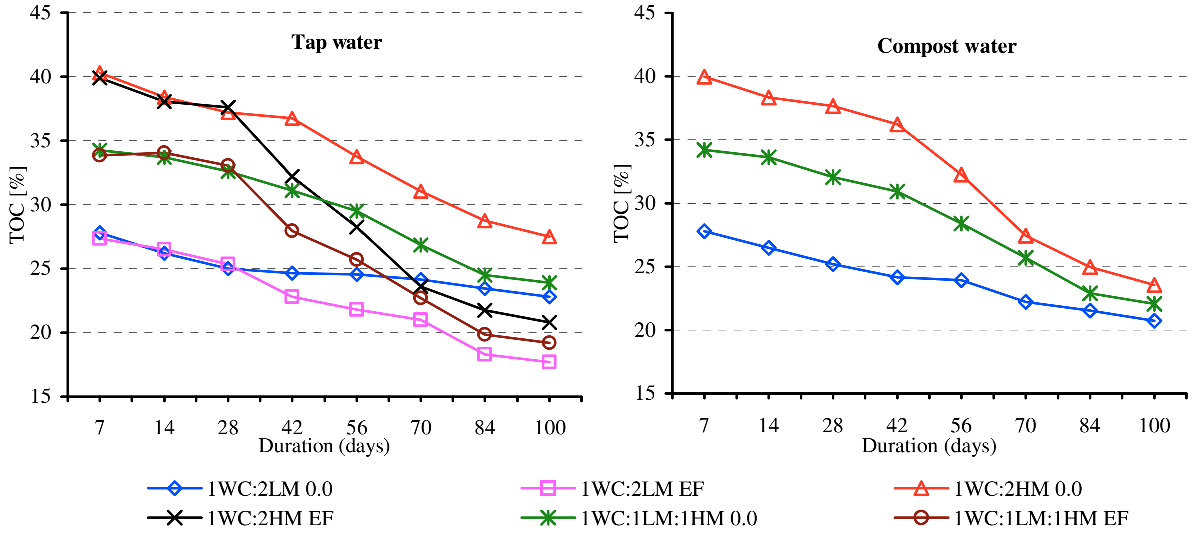


Fig. 4.21: Variation of total organic carbon during composting of wood under different studied treatments (data represent averages of three replicates)

The *EF* worms influenced the compost content of TOC, where the lowest value (17.7 %) was found in the 1WC:2LM mixture followed by 1WC:1LM:1HM (19.20 %) and 1WC:2HM (20.8 %). The earthworms promote such microclimatic conditions that increase the loss of organic carbon from substrates through microbial respiration in the form of CO_2 (VINCESLAS-AKPA & LOQUET, 1997; AIRE et al., 2002; SUTHAR, 2006). Microorganisms, Hormones, and enzymes presented in the worm gut accelerate mineralization of wood. Also, this decrease in TOC during composting may be resulted from the oxidation of carbon to CO_2 by compost water microorganisms during composting process (TIQUIA et al., 2002).

The effect of the studied treatments on the compost content [%] of total extractable carbon (TEC) was illustrated by Figure 4.22 (Table A.21). TEC of the compost displayed a similar trend to TOC. The different treatments confirmed that TEC decreased predominantly during the composting process due to the intense mineralization process. Throughout the composting process the compost content of TEC can be summarized in the following points:

a) The decreasing rate of TEC content in wood mixed with HM was higher than that in the wood mixed by LM. This is due to high degradation rate of soluble carbon in HM and his positive effect on wood mineralization,

b) The content of TEC was little decreased with the increase of incubation period,
c) The compost moisted by tap water and uninfected by worms have a high content of TEC compared to that associated with the *EF* worms and continued irrigated by compost water treatments, and
d) The arrangement of the tested mixtures according to its effect on the compost content of TEC was 1WC:2HM > 1WC:1LM:1HM > 1WC:2LM.

This trend is also due to high amount of TEC in the initial HM treatments. TEC values in the final products are affected by the initial C:N ratio of the raw materials. Finally, it can suggest that HM, *EF* worms and compost water microorganisms enhanced the decomposition and humification rate of *QR* wood, which correspondingly reducing TEC content. These results are in agreement with the results obtained by (KAUSHIK & GARG, 2004; WONG et al., 2006).

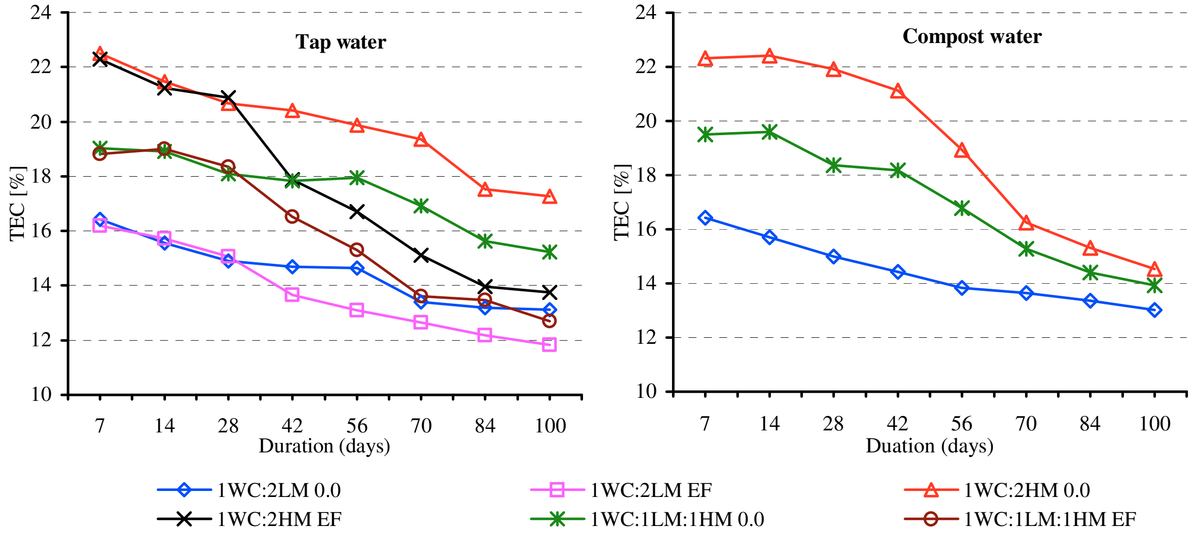


Fig. 4.22: Changes in total extractable carbon during composting of wood under different studied treatments (data represent averages of three replicates)

4.1.2.6. Total carbon, total nitrogen, C:N ratio and pH value

Data in Figure (4.23) and illustrated by Table (A. 22) showed the compost values of total carbon (TC) as affected by different studied factors. Under different studied treatments, the TC content [%] decreased with the increasing of composting period. Generally, initial TC values with in the range of 29.10 to 43.0 %, while the final TC ranged between 21.20 and 32.70 %. The highest decreasing rate was noted in the mixtures of wood and HM, while the lowest rate was found in the wood mixed by LM. Similarly as showed in the behavior of TOC, TC contents are affected by the used water and worms. High decreasing rate was shown in the treatments infected by *EF* worms followed by the other continued moisted by compost water, while the mixtures irrigated by tap water and uninfected by worms came belated. This trend reflects the high mineralization rates of *QR* wood under the influence of HM, *EF* and compost water. Worms and compost water microorganisms accelerated the decomposition of OM in wood. Throughout the composting process the compost content of TC in 1WC:2HM was the highest followed by 1WC:1LM:1HM and then 1WC:2LM. Also, this trend is affected by the amount of TC in the raw materials which it was the highest in HM. However, the high decreasing rate of TC was found in the HM treatments. It could be explained by HM contain a high amount of available carbon which encourages his decomposition by microorganisms and worms (EDWARDS, 2004; VEIJALAINEN et al., 2007; DESALEGN et al., 2008). Also, this trend may be related to the HM contain a high proportion of nutrients which provided the growth and reproduction of microbes and worms, and consequently accelerate the mineralization of wood.

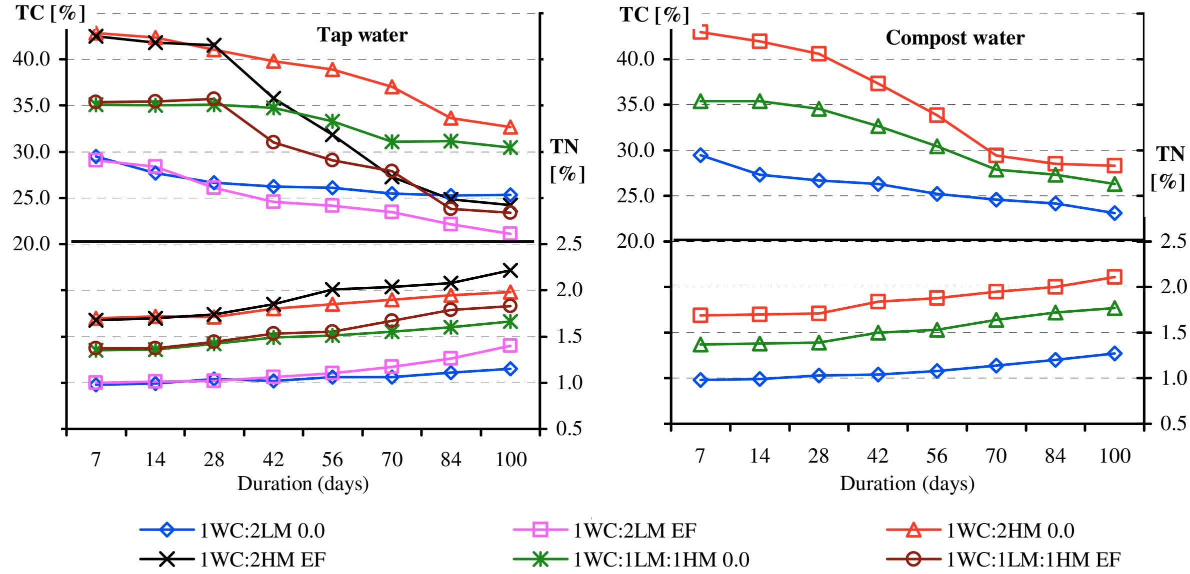


Fig. 4.23: Variation of total carbon and nitrogen content during composting of wood under different studied treatments (data represent averages of three replicates)

In contrast, data in Table (A. 23) and illustrated by Figure (4. 23) show that, the content [%] of total nitrogen (TN) which it was increase with increasing the incubation period. TN contents of all the treatments increased comparing with those of compost primary period, which indicated, during the wood composting, nitrogen could accumulate to certain extend when decomposing of organic matter. The highest TN content mixtures that are contain HM, while the lowest one that is containing LM. The highest values of TN were found in the mixture of 1WC:2HM followed by 1WC:1LM:1HM and 1WC:2LM. This may be due to the high amount of TN in the HM compared to LM. The increase in TN of different composted materials may be due to concentration effect because of biooxidation of OC during composting. Within each mixed ratio and during the first month no differences were found among different treatments.

After one month and because each mixing ratio are divided to three sub treatments, the high nitrogen content was observed in the treatment infected by *EF* worms. The lowest TN content was noted in the tap water uninfected treatment. The treatment continued irrigate by compost water came with intermediate values for TN. This clear trend could be explained by HM, *EF* worms and compost water microorganisms enhanced oxidation of non-nitrogenous organic materials and partially the N-fixation by non-symbiotic nitrogen fixers (HELLAL, 2007). The inoculating worms accelerated the decomposing of the organic matter in *QR* wood and accumulate nitrogen in the final product (cast). It also suggested that the earthworm also enhances the nitrogen levels of the substrate by adding their excretory products, mucus, body fluid, enzymes and even through the decaying tissues of dead worms in vermicomposting sub-system (SUTHAR, 2007). Also, the increase in total nitrogen during the composting process might be due to the activity of nitrogen fixing bacteria which was expected to exist in the compost pots. These bacteria have the capability to fix N_2 from the air to NO_3 contained in the pots. Also, Earthworms had a great impact on nitrogen transformation in the wood compost. The increase in TN value is as result of carbon loss and probably because of mineralization of organic matter (KAUSHIK et al., 2004*)*. Mixtures with a high lignocellulose content normally show low N losses during the composting process (SANCHEZ-MONEDERO et al., 2001). The final nitrogen content of compost is dependent on the initial N present in the raw materials and the extent of decomposition (HUANG et al., 2004; VEIJALAINEN et al., 2007).

The C:N ratio is one of the factors used to indicate compost maturation. C:N ratio of substrate material reflects the organic waste mineralization and stabilization during the process of decomposition. A C:N ratio of 20 or less is accepted as mature compost and reflects a satisfactory degree of organic wastes (SINGH et al., 2009). The results in Table (A. 24) and illustrated by Figure (4. 24) showed the C:N ratio of *QR* wood compost as affected by different studied treatments. The initial C:N ratio with in the range of 25.0 to 30.0. Final C:N ratios were in the range of 10.9 to 22.1. The data reflects the values of TC and TN, as TN increase and TC decrease, it should be C:N ratio decreased. The lowest C:N ratio value was recorded to the mixture of 1WC:2HM followed by 1WC:1LM:1HM and 1WC:2LM. In this study, the C:N ratio of the composted material was lower than the initial feed mixture and the highest reduction was in vermicompost processed by *EF* worms. Within each mixing ratio and after one month there was a clear effect of the studied sub treatments. The treatment infected by *EF* worms gave the lowest value of C:N ratio, while the highest value recorded to the uninfected and irrigated by tap water treatments. It can suggest that the HM, *EF* worms and compost water enhanced mineralization process during decomposition of wood. The loss of carbon as CO_2 through microbial respiration and added of nitrogenous excretory material may be the reason of decreasing C:N ratio of the substrate (GARG et al, 2006; SUTHAR, 2007).

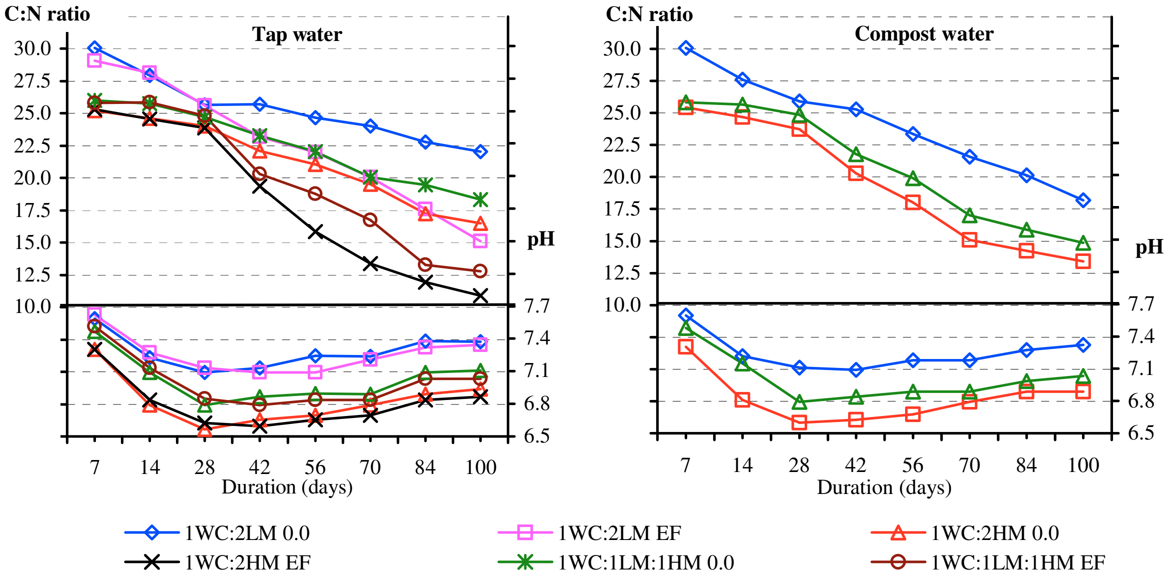


Fig. 4.24: Variation of C:N ratio and pH during composting of wood under different studied treatments (data represent averages of three replicates)

Also, data in Figure (4. 24) which recorded in Table (A. 25) showed the effect of different examined factors on compost pH value. During the composting process, the pH level of all pots dropped during the first 28 days after that it was increase and remained relatively unchanged after day 84. This trend reflects the high humification rate in the first period (28 days) compared to the others. Also, this shift of pH could be attributed to the bioconversion of the organic material into other various intermediate species of the organic acids (NDEGWA & THOMPSON, 2000). The increase of pH in composting pots during the composting process (after 28 days) could be due to the production of ammonium as a result of the ammonification process (HUANG et al., 2004). Throughout the composting process the pH value of the 1WC:2LM mixture was the highest followed by 1WC:1LM:1HM and finally 1WC:2HM mixture. This may be due to the high amount of OC in HM, produced high amounts of CO_2 and organic acid, and consequently decreasing pH. Also, in each mixing ratio and during composting period, there is a small difference among the treatments continued irrigated with compost water and the other moisted by tap water and uninfected by worms. Clearly, the lowest pH value was recorded to the treatment irrigated with tap water after one month and infected by *EF* worms. Earthworms enhanced mineralization of nitrogen and phosphorus in to nitrates /nitrites and orthophosphates, bioconversion of organic materials in to intermediate species of organic acids (NDEGWA et al., 2000).

4.1.2.7. Humic substances and humification parameters

Composting was the process that polymerizes the decomposed organic matter into humic substance (SANCHEZ-MONEDERO et al., 2002). In this study, the humic substance content [%] did not show a consistent trend during composting period (Fig. 4.25, Table A.26). This phenomenon might result from the characteristics of the humic substance, which was formed in time limited composting by microorganisms and was different from that in nature. Humic substance formed in the composting could be decomposed partly by microorganisms (CHEFETZ et al., 1998; TOMATI et al., 2000; ADANI & SPAGNOL, 2008). Throughout the composting process, HA content increased until the day 42 after that it was decreased till the day 84 which it increased again. In the same context, data in Figure 4.26 (Table A. 27) observed that the fulvic acid (FA) content [%] was increase until the day 70 and after that it was decrease till the end of incubation period. Data also showed the HA content were higher than the FA content of all mixtures during composting period (WONG et al., 2006). This may be due to the chemical composition of the compost raw materials. The low molecular weight FA is aliphatic and have higher O but lower C contents than the high molecular weight HA (aromatic). Therefore, the proportion and structure of wood components (cellulose, hemicellulose and lignin) and their degradability affected the HA and FA forming. The wood mixed with HM gave the highest values of either HA or FA, while the lowest values recorded to the mixture of wood and LM. These results may be attributed to the high degradation and humification rate of HM. The HM enhanced microbial activity, increase decomposition rate of wood compared to the effect of LM (VEEKEN et al., 2000; DESALEGN et al., 2008). Moreover, HM contain a high amount of HA and FA compared with those in LM (Table 3.1).

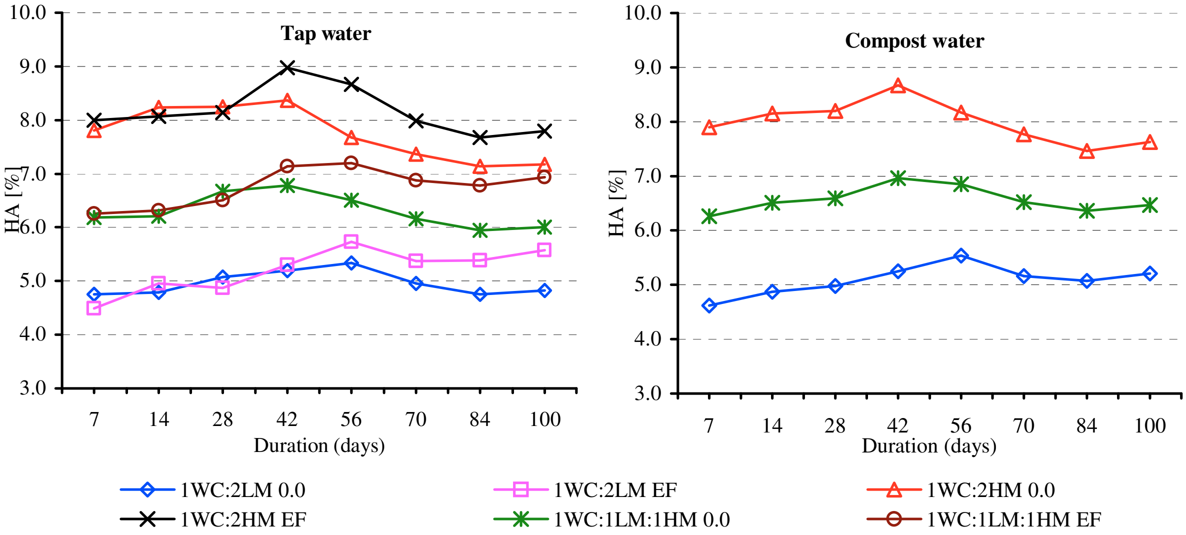


Fig. 4.25: Variation of humic acid content during composting of wood under different studied treatments (data represent averages of three replicates)

The arrangement of the used mixtures in terms of HA and FA contents was 1WC:2HM > 1WC:1LM:1HM > 1WC:2LM. It can conclude that, increases of HA and FA content at the beginning may be reveal to the high content of soluble organic substances and the high activity of microorganisms. In the other side, increase of HA content and decrease FA in the latter period may be due to transformation of FA to create stable compounds of HA or consumption of the FA by microbial activity (AIRE et al., 2002; MA & WU, 2002; DESALEGN et al., 2008). In addition, increase HA acid in the final stage may be related to the high amount of aromatic compounds in lignin, whereas HA is aromatic. Also, the results in Figures 4.25 and 4.26 show no differences of both HA and FA values were fount within each mixture during the first month. After month and due to each mixture was classified to three treatments, there are a high variation were appear. The highest values of either HA or FA were evident in the treatments irrigated by tap water and infected by *EF* worms. The low values recorded to the mixtures moisted by tap water and uninfected by worms. The mixtures continued irrigated by compost water came directly in the standings after that infected by *EF* worms. This trend may be due to high contents of nutrients and microorganisms in compost water compared that found in tap water which affected the decomposition rate. This trend also demonstrated that the *EF* worm's achieved the highest rate of wood degradation (VINCESLAS-AKPA & LOQUET, 1997; EDWARDS, 2004; KAUSHIK & GARG, 2004; GARG et al., 2005; WONG et al., 2006). It can suggest that compost water microorganisms and enzymes and hormones in worm gut able to dissolve the bonds linked the carbon compounds in wood.

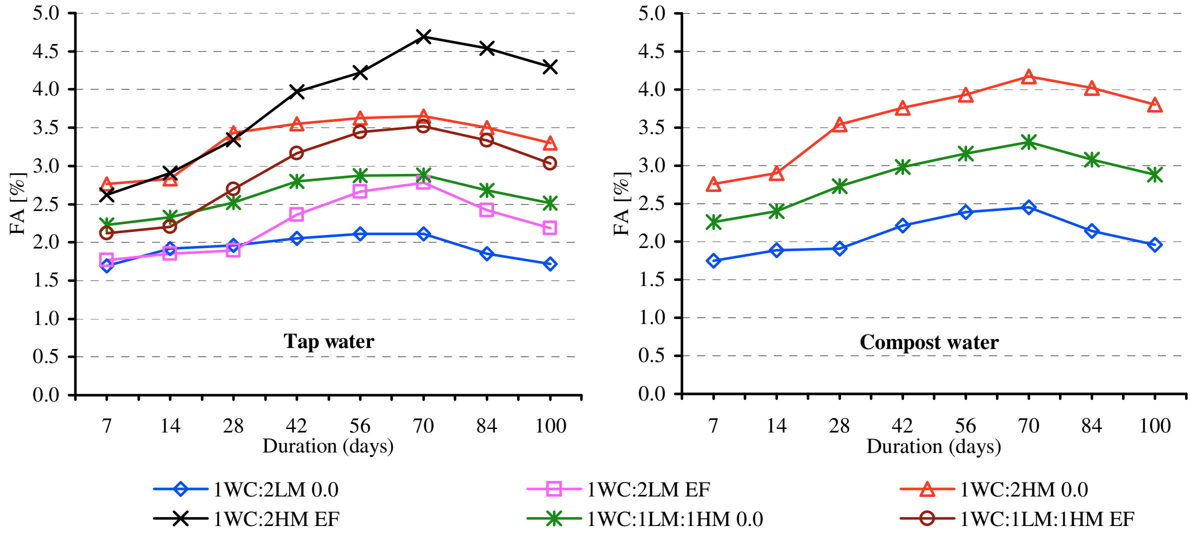


Fig. 4.26: Variation of fulvic acid content during composting of wood under different studied treatments (data represent averages of three replicates)

In order to evaluate the maturity level of the organic matter composted through the composting process, humification parameters have been used to discriminate stabilized form (CIAVATTA et al., 1993). The calculated values [%] of humification degree (DH) and humification rate (HR) were summarized in Tables (A.28 and A.29) and illustrated by Figures (4.27 and 4.28). Throughout the composting process, the values of DH and HR of all compost mixtures were increased. The obtained data of all compost mixtures observed a more regular increasing trend during composting. The raising rate reduced after the day 70, meanly the compost materials reached to the stability phase. Also, this may be related to the difficulty degradation of lignin compounds. Data also showed that the final DH and HR values of all mixtures were higher than the initial values. This could be explained by the degradation of organic matter during the composting period. The highest values of either DH or HR were recorded to the wood mixed with HM while the lowest values recorded to the LM mixture. For both DH and HR values it can order the used mixtures as 1WC:2HM was the highest followed by 1WC:1LM:1HM and 1WC:2LM. This may be due to high decomposition rate of HM compared to LM mixture (BANEGAS et al., 2007).

Also, degradation rate of wood mixed with HM was higher than that mixed with LM. High amount of TN, soluble carbon and microorganisms in HM may be improved and raised the degradation rate of wood (VEIJALAINEN et al., 2007; DESALEGN et al., 2008). During the first 30 days no differences in either DH or HR values founded between different studied treatments in each mixing ratio. These variations appeared evident after that and till the end of composting period. The highest values for both DH and HR recorded to the mixtures infected by *EF* worms, followed by the other continued irrigated by compost water and then the treatments moisted by tap water and free from worms. Microbes and enzymes in the worm gut, microorganisms in compost water, increasing degradation and decomposition of OM (CIAVATTA et al., 1993;

BERNAL et al., 1998; DESALEGN et al., 2008). At the end of experiment the highest values of either DH or HR (87.90 and 58.10 % respectively) founded in the mixture of 1WC:2HM and infected by *EF* worms (Fig. 4.27, 28). While the lowest values of 50.00 and 28.70 % for DH and HR respectively, were appearing in the treatment of 1WC:2LM moisted by tap water and uninfected by worms (EDWARDS, 1988; KAUSHIK & GARG, 2004; SUTHAR, 2006).

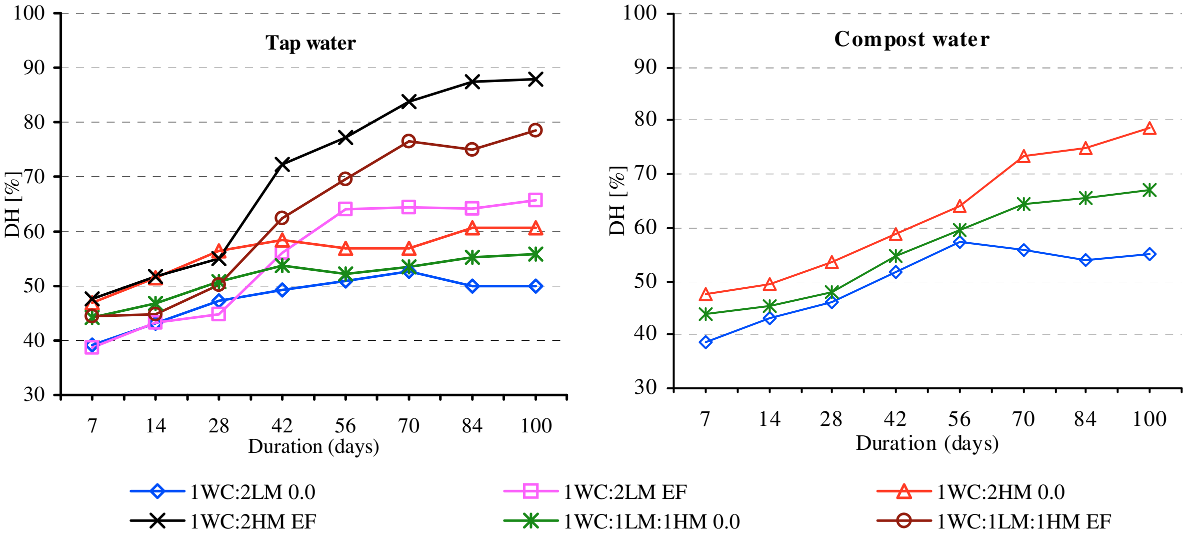


Fig. 4.27: Changes in degree of humification during composting of wood under different studied treatments (data represent averages of three replicates)

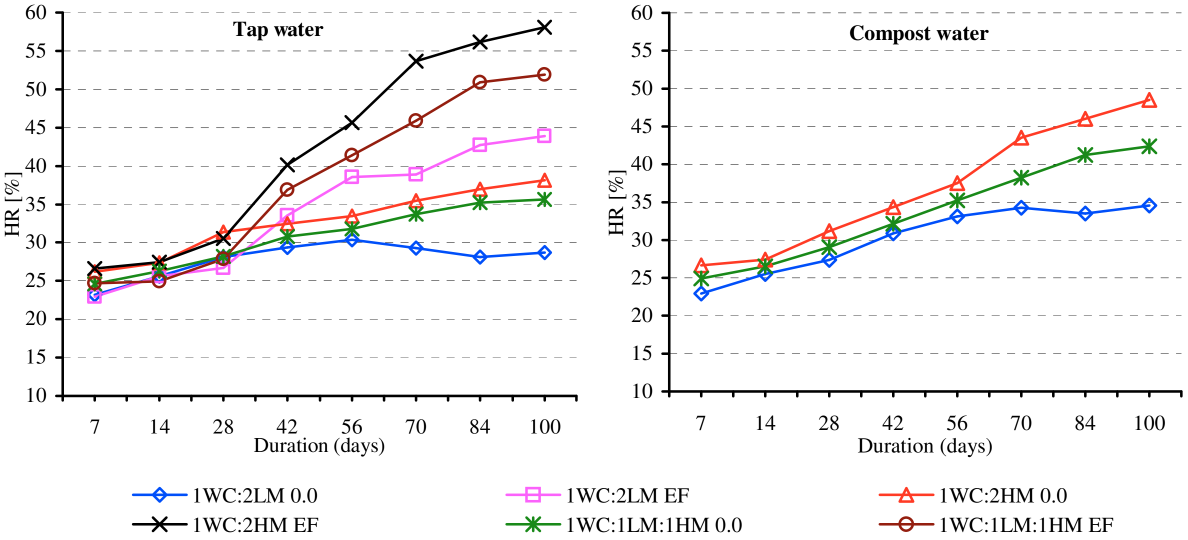


Fig. 4.28: Changes in humification rate during composting of wood under different studied treatments (data represent averages of three replicates)

On the contrary, the calculated values of humification index (HI) of the used mixtures were decrease gradually with the increasing of composting period (Figure 4.29 and Table A.30). This trend may be resulted from the increase of decomposition and humification of humic substances with the increase of incubation period (CIAVATTA et al., 1993; DESALEGN et al., 2008). As suggested by CIAVATTA et al. (1990, 1993), compost that had lower HI value should be higher in the maturity rate. In this respect, CIAVATTA et al. (1990) confirmed that the well stabilized compost should be characterized by ≤ 0.5 value of HI. The obtained data show that, the value of HI in the mixture of 1WC:2HM was lower than the other mixtures. Within each mixed ratio no differences of HI values were found during the first month. Throughout after passage month and till the end of composting, the lowest value of HI observed in the treatments infected by *EF* worms, while the highest values recorded to the others moisted by tap water and uninfected by worms.

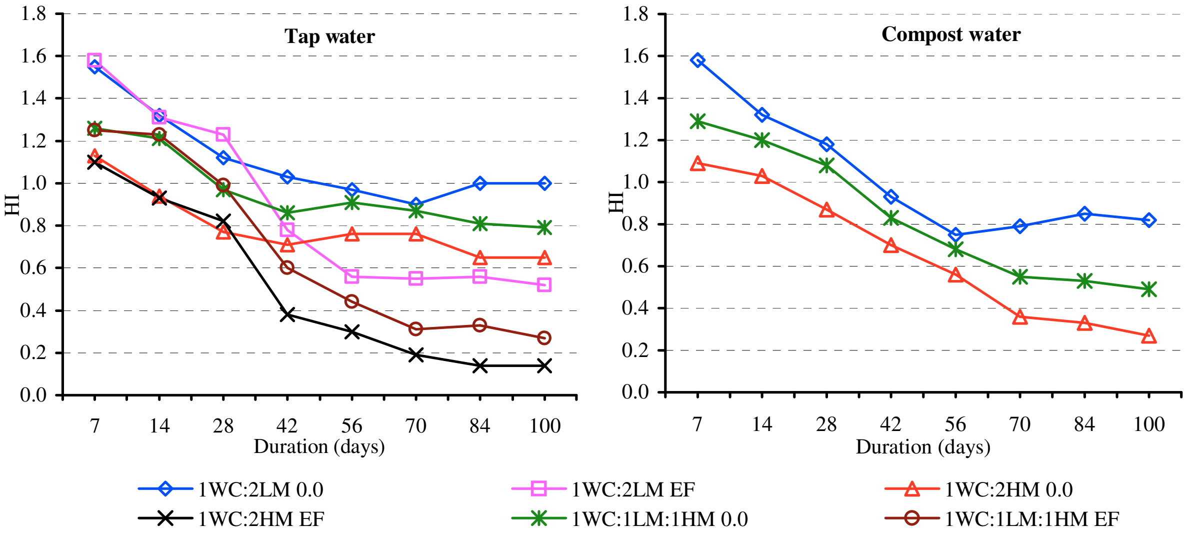


Fig. 4.29: Changes in humification index during composting of wood under different studied treatments (data represent averages of three replicates)

At the end of experiment, the lowest values of HI were 0.14, 0.27 and 0.52 for the mixture of 1WC:2HM+*EF*, 1WC:1LM:1HM+*EF* and 1WC:2LM+*EF* respectively (SUBLER et al., 1998; EDWARDS, 2004). Whereas, the highest values of HI in all studied mixtures recorded to the treatment irrigated by tap water and uninfected by worms. It was 1.00, 0.79 and 0.65 for 1WC:2LM, 1WC:1LM:1HM and 1WC:2HM respectively. These may be due to the HM contain high amount of HA and FA compared to those in LM. These trends also reflect the high degradation rate of HM treatments explained by high amounts of HA and FA to the amount of TEC. Moreover, Low decomposition rat of the wood mixed with LM compared to that mixed by HM might be the other reason. *EF* worms and compost water influenced the forming of HA and FA which consequently affected the HI values. High amount of total extractable carbon and low amount of HA and FA are the reason of raising HI values of LM treatments. From the previous dissection it can be concluded that, the compost produced from wood mixed with HM was more mature, stable and better than that produced from the other mixed with LM (CIAVATTA et al., 1990; MA & WU, 2002).

4.1.2.8. Physical and chemical properties of compost

The results of the physicochemical characterization of the wood compost are presented in Tables (4.10, 11). Data in Table 4.10 showed the high significant differences between different studied mixtures on compost physicochemical properties. Values of all studied properties were significantly increased as HM presence or increase (except pH and C:N ratio). These data observed that, the compost produced from 1WC:2HM mixture gave the high value (0.64 g cm^{-3}) of bulk density (BD) followed by 1WC:1LM:1HM (0.56 g cm^{-3}) and finally 1WC:2LM (0.53 g cm^{-3}). This trend may be due to high decomposition rate of HM treatments compared to LM mixtures. Moreover, increases mineralization rate of the wood treated with HM should be increase ash content and consequently increase BD (RAVIV et al., 1987; NATHAN, 2004). The values of water holding capacity (WHC) of compost produced from wood mixed with HM was higher than that of wood mixed with LM. The highest value (168.22 %) of WHC was recorded to 1WC:2HM, while the lowest value (154.45 %) observed to 1WC:2LM. This could be explained by the high amount of TOC in HM compost characterized by a high surface tension which retained more amounts of water (MA & WU, 2002). Electrical conductivity (EC) in compost of wood mixed by HM was higher than that in compost produced from wood mixed with LM. This reflects the high mineralization rate of *QR* wood especially when it mixed by HM (KALE, 1998; MASCIANDARO et al., 1997; DESALEGN et al., 2008).

Table 4.10: Chemical and physical properties of wood compost as affected by different mixing ratios (data represent averages of three replicates)

Parameters Mixing ratio	BD [g cm^{-3}]	WHC [%]	EC [dS m^{-1}]	pH	OM [%]	TOC [%]	CEC [cmol kg^{-1}]	TC [%]	TN [%]	C/N ratio
1WC:2LM	0.53 c	154.45 c	3.93 c	7.35 a	34.30 c	20.16 c	46.82 c	23.29 c	1.36 c	17.13 a
1WC:2HM	0.64 a	168.22 a	4.89 a	6.95 c	39.10 a	23.87 a	51.30 a	28.14 a	2.22 a	12.68 c
1WC:1LM:1HM	0.56 b	162.34 b	4.27 b	7.12 b	35.40 b	21.80 b	48.12 b	26.23 b	1.79 b	14.65 b
LSD $_{0.05}$	0.02	4.53	0.02	0.15	0.70	0.63	0.95	0.67	0.12	1.33

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3)

The values of pH in HM treatments were lower than that in LM treatments. Production of CO_2 and organic acid by microbial decomposition during vermicomposting lowers the pH of substrate (SULLIVAN & MILLER, 2001; GARG et al., 2005). The wood compost produced from HM treatments contains a high amount of OM, TOC, and TC in comparison with those in the LM mixtures. This might be caused by high amount of OM in HM compared to LM (Table 3.1). Total nitrogen content (TN) and cation exchange capacity (CEC) in compost of wood with HM were higher than that of wood mixed by LM. This is due to high mineralization rate and decreased dry matter of HM and his wood treatments. High humic fractions and increasing the fine particles of HM treatments can result in increased CEC (ALBANELL et al., 1988; Nathan, 2004). The C:N ratio gave the normal direction which it depended on the trend of both amount of TC and TN.

The effects of water quality and earthworm infection on compost physical and chemical properties are summarized in Table 4.11. The data showed the high significant variations among the *EF* worms treatment (T3), the continuance irrigated with compost water treatment (T1) and the other treatment irrigated with tap water and uninfected by worms (T2). Means worms and compost water enhanced mineralization rate of the studied mixtures (EDWARDS, 1988; EDWARDS; 1998; SUBLER et al., 1998; EDWARDS, 2004). The high values of BD, EC, CEC, TN and C/N ratio were recorded to the treatment infected by *EF* worms, while the lowest values were in the T2 treatment.

Table 4.11: Chemical and physical properties of wood compost under different water types and worms infection (data represent averages of three replicates)

Parameters Water & worm	BD [g cm^{-3}]	WHC [%]	EC [dS m^{-1}]	pH	OM [%]	TOC [%]	CEC [cmol kg^{-1}]	TC [%]	TN [%]	C/N ratio
T1	0.56 b	163.11 b	4.60 b	7.18 b	36.80 b	21.98 b	47.99 b	25.71 b	1.76 b	14.61 b
T2	0.46 c	172.23 a	3.98 c	7.38 a	40.81 a	24.82 a	43.72 c	29.27 a	1.71 c	17.12 a
T3	0.68 a	146.15 c	5.20 a	7.04 c	31.11 c	19.02 c	53.52 a	22.68 c	1.84 a	12.33 c
LSD $_{0.05}$	0.04	5.12	0.03	0.12	1.30	0.62	0.83	0.36	0.02	1.50

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3), T1 = Compost water all composting period and without worms, T2 and T3 = Tap water after one month compost water without and with worms respectively

The high value (1.84 %) of TN was found in the worm treatment (T3), while the lowest value (1.71 %) was in T2 treatment. This may be reveals to the addition of nitrogen in the form of mucus, nitrogenous excretory substances, growth stimulating hormones and enzymes from earthworms (TRIPATHI & BHARDWAJ, 2004). The compost contents of WHC, OM, TOC and TC took an adverse value. For example, the high value (172.23 %) of WHC was recorded to T2 treatments followed by the T1 treatment (163.11%) and finally T3 treatment (146.15 %). This trend reflects low OC content in the *EF* worm treatment, resulted from high decomposition rate. Also, the data in Table 4.11 showed the compost pH value was clearly influenced by the studied factors. The lowest value (7.04) of compost pH was appearing in T3 treatment, while the highest value (7.38) recorded to T2 treatment. This may be due to the worms and compost water microorganisms enhanced decomposition and formation of CO_2 organic acids. *QR* wood was more response to degrade and decompose when mixed by HM and infected by *EF* worm compared to the other factors.

4.1.2.9. Macro and micro nutrients content of wood compost

Total macro and micro nutrients content of wood compost

The effect of the studied factors on the compost content of total nutrients is summarized in Tables 4.12 and 4.13. These data reveals that, the values of all nutrients influenced by HM and LM substances. There are a high significant differences of total nutrients content (except Cu) in compost which affected by the studied mixtures. The analytical data indicates that the Ca is the predominate cation followed by K, Fe, Mg, P, Mn, Zn, and Cu. The highest compost content of P, Mg, K, Zn and Cu was recorded to the mixture of 1WC:2HM followed by 1WC:1LM:1HM and then 1WC:2LM mixture. In contrast, compost produced from 1WC:2LM mixture contains the highest quantity of Ca, Fe and Mn. This trend might be based on the amount of these elements in the used raw materials (Table 3.1). Also, mixed wood with different nitrogen resources (HM and LM) led to high variations in his mineralization rate, which affected the nutrients content in the final product.

Table 4.12: Total macro and micro nutrients content of wood compost as affected by different mixing ratios (data represent averages of three replicates)

Parameters / Mixing ratio	Macronutrients [g kg^{-1}]				Micronutrients [mg kg^{-1}]			
	P	Ca	Mg	K	Fe	Mn	Zn	Cu
1WC:2LM	0.63 c	12.90 a	1.14 c	4.85 c	5748.45 a	387.86 a	44.92 c	16.33 a
1WC:2HM	2.18 a	5.45 c	1.65 a	7.13 a	2681.66 c	153.25 c	77.18 a	17.04 a
1WC:1LM:1HM	1.59 b	8.08 b	1.32 b	5.82 b	4189.89 b	240.76 b	49.66 b	16.28 a
LSD $_{0.05}$	0.12	0.48	0.15	0.63	160.83	43.65	3.55	0.78

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3)

Regarding to the effect of water quality and earthworms, data in Table 4.13 showed the high significant values of all studied nutrients (except Cu) in compost affected by *EF* worms compared to the others. No significant differences in the compost content of all nutrients, between the treatments continued irrigate by compost water (T1) and the other moisted by tap water (T2), with the high values recorded to T1 treatment. The high significant effect of *EF* worms on the values of examined nutrients may be due to the high ability for *EF* worms to eat and digest the *QR* wood compared to the microorganisms in compost and tap water. The positive impact of the used worms may be resulted from the earthworm processed waste material contains high concentration of exchangeable nutrients, due to enhanced microbial activity during the vermicomposting process, which consequently enhanced the rate of mineralization (SUTHAR, 2007; SINGH et al., 2009). The enhancement of compost water in the values of studied nutrients may be resulted from chelated these elements from compost water by organic matter (HE et al., 2001; GARG, 2006).

Table 4.13: Total macro and micro nutrients content of wood compost under different water types and worms infection (data represent averages of three replicates)

Parameters / Water & worm	Macronutrients [g kg^{-1}]				Micronutrients [mg kg^{-1}]			
	P	Ca	Mg	K	Fe	Mn	Zn	Cu
T1	1.38 b	9.15 b	1.35 b	5.93 b	4287.33 b	278.66 b	52.19 b	16.60 a
T2	1.27 b	8.85 b	1.28 b	5.88 b	4282.46 b	276.23 b	52.27 b	16.62 a
T3	1.85 a	9.70 a	1.43 a	6.22 a	4313.94 a	289.75 a	56.31 a	16.65 a
LSD $_{0.05}$	0.34	0.69	0.17	0.27	17.25	8.58	2.11	0.15

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3), T1 = Compost water all composting period and without worms, T2 and T3 = Tap water after one month compost water without and with worms respectively

Available macro and micro nutrients content of wood compost

The effects of the studied factors on the compost content of available nutrients are summarized in Tables 4.14 and 4.15. The data showed the same trend of total macro and micro nutrients in compost. Compost available N content recorded the highest value followed by Ca, K, Mg, Fe, Mn, P, Zn, and Cu. Values of available N, P, Mg, K, Zn and Cu in compost produced from wood mixed with HM were higher than those in the other prepared from wood and LM. The highest values of these nutrients founded in 1WC:2HM followed by 1WC:1LM:1HM and finally 1WC:2LM mixture. on the other hand, the highest values of 2585.38, 209.13 and 69.52 [mg kg^{-1}] for available Ca, Fe and Mn respectively seem to be in the compost prepared from 1WC:2LM mixture. These trends reflect the chemical composition of the used raw materials (Table 3.1). Also the obtained data demonstrates the positive impact of either HM or LM on the mineralization of *QR* wood.

Table 4.14: Available macro and micro nutrients content of wood compost as affected by different mixing ratios (data represent averages of three replicates)

Parameters / Mixing ratio	Macronutrients [mg kg^{-1}]					Micronutrients [mg kg^{-1}]			
	N	P	Ca	Mg	K	Fe	Mn	Zn	Cu
1WC:2LM	3511.88 c	37.87 c	2585.38 a	437.72 c	482.74 c	209.13 a	69.52 a	9.29 b	1.15 a
1WC:2HM	5526.05 a	131.06 a	1392.27 c	633.54 a	780.27 a	136.64 c	29.84 c	16.83 a	1.21 a
1WC:1LM:1HM	4622.26 b	95.58 b	1619.33 b	506.83 b	655.29 b	152.60 b	43.15 b	12.27 b	1.17 a
LSD $_{0.05}$	215.34	26.15	171.45	48.22	126.13	13.37	12.88	3.64	0.22

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3)

The effects of the used water and worm on the compost available nutrients content are presented in Table 4.15. The data reveals that under different studied treatments (T1, T2 and T3) the high significant differences in the compost content of available nutrients were recorded to *EF* worm treatment (T3) with the exception for Zn and Cu. All examined nutrients seem with the highest values in *EF* worm treatment (T3) followed by T1 and finally T2 treatment. No significant variations in the compost contents of available Zn and Cu between the studied treatments. Also, there is no differing significantly in the values of Fe and Mn among T1 and T2 treatments, with the highest values for T1. The *EF* worm enhanced the nutrients mineralization rate due to enhanced microbial activity during the vermicomposting process by his gut microorganisms (SUTHAR, 2007). For example, the enhanced P level in ready vermicompost suggests the release of phosphorous in the available form is performed partly by earthworm gut phosphatases and further release of P might be attributed to the P-solubilizing microorganisms present in worm casts (SUTHAR, 2007). Moreover, increased total macro and micro nutrients and CEC as showed previously might be causes increased available nutrients (GOYAL et al., 2005). The released of available nutrients might be attribute to soluble the nutrients by microorganisms presented in compost water (SINGH et al., 2009). High amount of nutrients in compost water which adsorbed by compost organic matter may be the other reason.

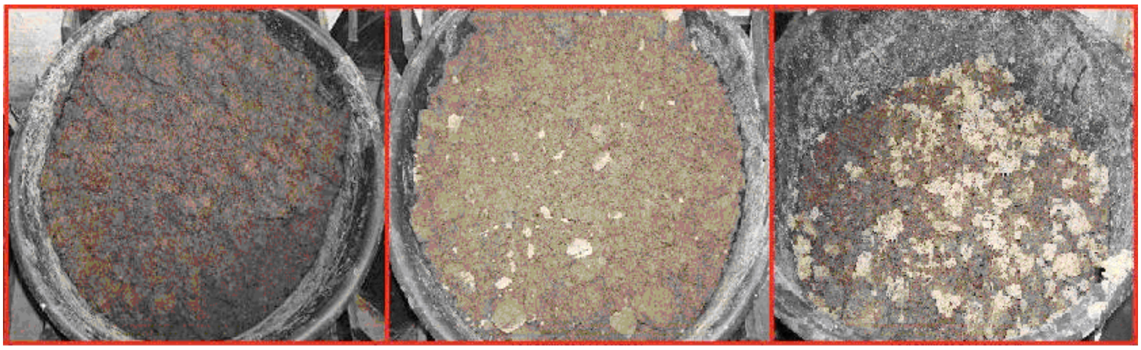
Table 4.15: Available macro and micro nutrients content of wood compost under different water types and worms infection (data represent averages of three replicates)

Parameters / Water & worm	Macronutrients [mg kg^{-1}]					Micronutrients [mg kg^{-1}]			
	N	P	Ca	Mg	K	Fe	Mn	Zn	Cu
T1	4544.80 b	82.96 b	1833.82 b	518.35 b	686.73 b	167.75 b	46.32 b	12.72 a	1.17 a
T2	4415.68 c	76.35 c	1773.70 c	491.48 c	661.01 c	160.14 b	45.55 b	12.76 a	1.16 a
T3	4751.37 a	95.19 a	1951.54 a	546.67 a	722.55 a	186.23 a	54.12 a	14.52 a	1.19 a
LSD $_{0.05}$	121.73	5.55	46.83	20.35	15.62	10.50	6.17	3.11	0.13

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3), T1 = Compost water all composting period and without worms, T2 and T3 = Tap water after one month compost water without and with worms respectively.

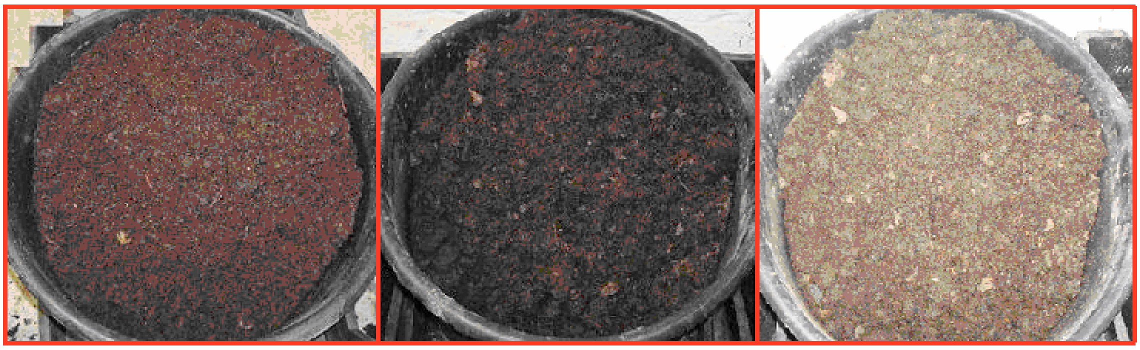
4.1.2.10. Compost color and odor properties

The compost was much darker in color than originally and had been processed more homogenous mixture after 30 days composting and 70 days of earthworm's activity. Figure 4.30 showed the large differences in color and texture among studied treatments compared to their status at the beginning of experiment (Figure A.4, 5). Based on darkening of color and the degree of homogeneity, the compost produced from 1WC:2HM mixture was browner, homogenous and ranked as first. The second order was observed to 1WC:1LM:1HM mixture, while the mixture of 1WC:2LM came last in the ranking. This trend reflects the degree of maturity of the studied mixtures, whereas 1WC:2HM was the best. Also, increase darkening of brown color in HM treatments may be due to high amount of decomposed organic acid and humic substances. The lighter color of 1WC:2LM mixture may be due to high amount of $CaCO_3$ in LM and low decomposition rate of his wood. With in each mixing ratio the mixture treated with *EF* worms (A) was much darker and homogenous compared to the others (B, C). Also, it can arranged as *EF* worms treatments was the first in term of color and homogeneity, the second was the treatments continued moisted with compost water (B) and finally the treatments irrigated with tap water and uninfected by worms (C) (Figure 4.30). Generally, the best treatment was (A) while the poorest is (C). This trend reflects high humification rate of A and B treatments compared to C treatments. *EF* worms and compost water microbes had a positive impact on the prepared compost. Increase the brightness of brown color is a guide to increase the rate of maturity. Generally, there are no offensive odors in the prepared compost with the exception of the treatments irrigated with tap water and uninfected by worms (C) (DRUILHE et al., 2002). This trend may be due to the worms and compost water microorganisms improved aeration, increased aerobic microbial activity, and limiting malodorous anaerobic activity (TIQUIA et al., 2002). As a result, malodorous fatty acids and methane levels may increase under anaerobic conditions (DRUILHE et al., 2002; NATHN, 2004).



(A) **(B)** **(C)**

1WC:2LM



(A) **(B)** **(C)**

1WC:2HM

(A) **(B)** **(C)**

1WC:1LM:1HM

Fig. 4.30: The treatments of *Quercus rubra* wood compost at the end of experiment

(A) Compost water for one month, after that tap water, and infected by *EF* worms
(B) Compost water for all composting period and without worm infection
(C) Compost water for one month, after that tap water, and without worm infection

4.1.3. Microstructure properties of wood vermicompost

Structure refers to the rigidity of particles that is, their ability to resist settling and compaction. Most decomposition during composting occurs on the surfaces of particles. As particle size reduces, the amount of surface area for decomposition increases (RYNK et al., 1992). Fine grain size has been a greater surface area to volume ratio. The small grain size is significant because the behavior of the compost or soil is dependent on electrical and chemical forces of attraction rather than contact friction grain to grain. Increase grain surface area means increase absorbed water and exchanged cations, which affected by the structure shape. From these rules the structure of compost was done to evaluate the homogeneity and relationship between surface area and the volume of compost particles.

The structure of wood vermicompost was viewed under scanning electron microscope (SEM) as shown in Figure 4.31. For further clarification the selected vermicompost samples were compared with a selective soil sample (used as a reference). The soil sample was characterized by 9.63 % OM content (see paragraph 3.1.4.4). The results in Figure 4.31-A, B, and C are the vermicompost samples produced from treatments of 1*QR*:2LM+*EF*, 1*QR*:3LM+*EF* and 1*QR*:2HM+*EF* respectively, while the micrograph of soil sample is presented in Figure 4.31, D. For more clarity, each sample was examined in two levels of magnification.

The SEM observation indicated significant differences among the studied vermicompost samples. There are clear differences among the vermicompost prepared from wood mixed by HM (Fig. 4.31, C) and the other mixed by LM (Fig. 4.31, A, B). Regarding to the structure shape, the micrographs observed that the vermicompost produced from the mixtures of wood and LM (Fig. 4.31-A, B) is sub-angular blocky, while the structure of vermicompost resulted from 1*QR*:2HM+*EF* mixture (Fig. 4.31-C) have been seen to exhibit a fiber-like basic microstructure with sticks which tended to associate in bundles. Also, the obtained results indicated the structure of vermicompost was homogenous since it has one shape of the structure forms. As well as, the particle sizes were more uniform, eliminating large pore spaces. Vermicompost sample seems to be heavily aggregated with single particles difficult to identify particularly for the vermicompost produced from mixed wood with LM (Fig. 4.31-A, B). The surface area of vermicompost sample showed the single particles packed together to form aggregates. Such aggregation is responsible for the uncertainty about the real surface area of vermicompost because the internal area is not fully accessible.

On the other hand, the studied soil seems to be heterogeneous under SEM. This is due to the presence of various forms of structure shapes (granular, angular and sub-angular blocky, prismatic, and crumb). The fragility of the soil structure is likely due to the electrostatic repulsion forces due to the positive charges present on the particle surface. Also, different weathering factors of soil sample leads to a random aggregation of particles of various shapes and dimensions. The selected soil sample was very poorly aggregated compared to vermicompost samples. The soil images show the paucity of organic material, or muscilages, available for binding of primary mineral particles in these soils. Predominate grain sizes in the images (Fig. 4.31-D) are silt and sand-sized particles. However, there was little evidence of durable particle adhesion or binding, via visible organic or mineral compound bridging, or any other soil aggregating mechanisms.

The homogeneity of vermicompost structure could be explained by vermicompost produced under controlled conditions especially each treatment resulted from a single source of raw materials. In contrast, different weathering factors and uncontrolled conditions may be the reasons of the heterogeneity of soil structure. It is true that many soil properties such as OM and clay contents, mineralogy, pH and bonding agents (e.g. iron oxides) contribute to structural stability. Soil containing more OM and clay fractions tends to erode less than those with sand or silt and low

OM contents (SIX et al., 2000). Moreover, different morphological feature occurred among vermicompost and soil might be due to their different chemical structure. The comparison of the micrographs of soil and vermicompost samples suggests that the surface area of vermicompost samples is higher than that founded in soil. The wood compost had lower bulk density and higher free air space values than the studied soil. The particle size of the vermicompost was smaller than that of the soil. Therefore surface area of vermicompost may be greater than the other in the same volume of soil (Figure 4.31). Within vermicompost samples, the highest ratio of surface area : volume was recorded to the mixture of 1*QR*:2HM+*EF* (Fig. 4.31-C1, C2), while there are no differences evident among the vermicompost produced from 1*QR*:2LM+*EF* (Fig. 4.31-A) and 1*QR*:3LM+*EF* treatments (Fig. 4.31-B). It is expected that the greatest impact on soil properties may be for the vermicompost produced from mixing wood with HM when compared with the other wood mixtures (LM).

Application of wood and HM vermicompost to soil may be raise the ratio of soil surface area to volume than other mixtures of wood vermicompost. Also, it can suggest that application of vermicompost to soil will adhering soil particles to each other, decrease soil bulk density, increase porosity and consequently raise interaction surface area. In addition, increase soil surface are will raise the amount of exchangeable cation and accordingly increase available amount of plant nutrients. It resists compaction in fine-textured soils and increases water-holding capacity and improves soil aggregation in coarse-textured (sandy) soils (BALDOCK, 2002).

Finally, from the point of view of practical soil management the stability and the development of soil structure towards the effects of OM content is largely conferred by roots, hyphae, clay content and by the quality of applied compost. Thus, the application of mature wood compost will improve the arrangement of soil aggregates and consequently the stability of soil structure.

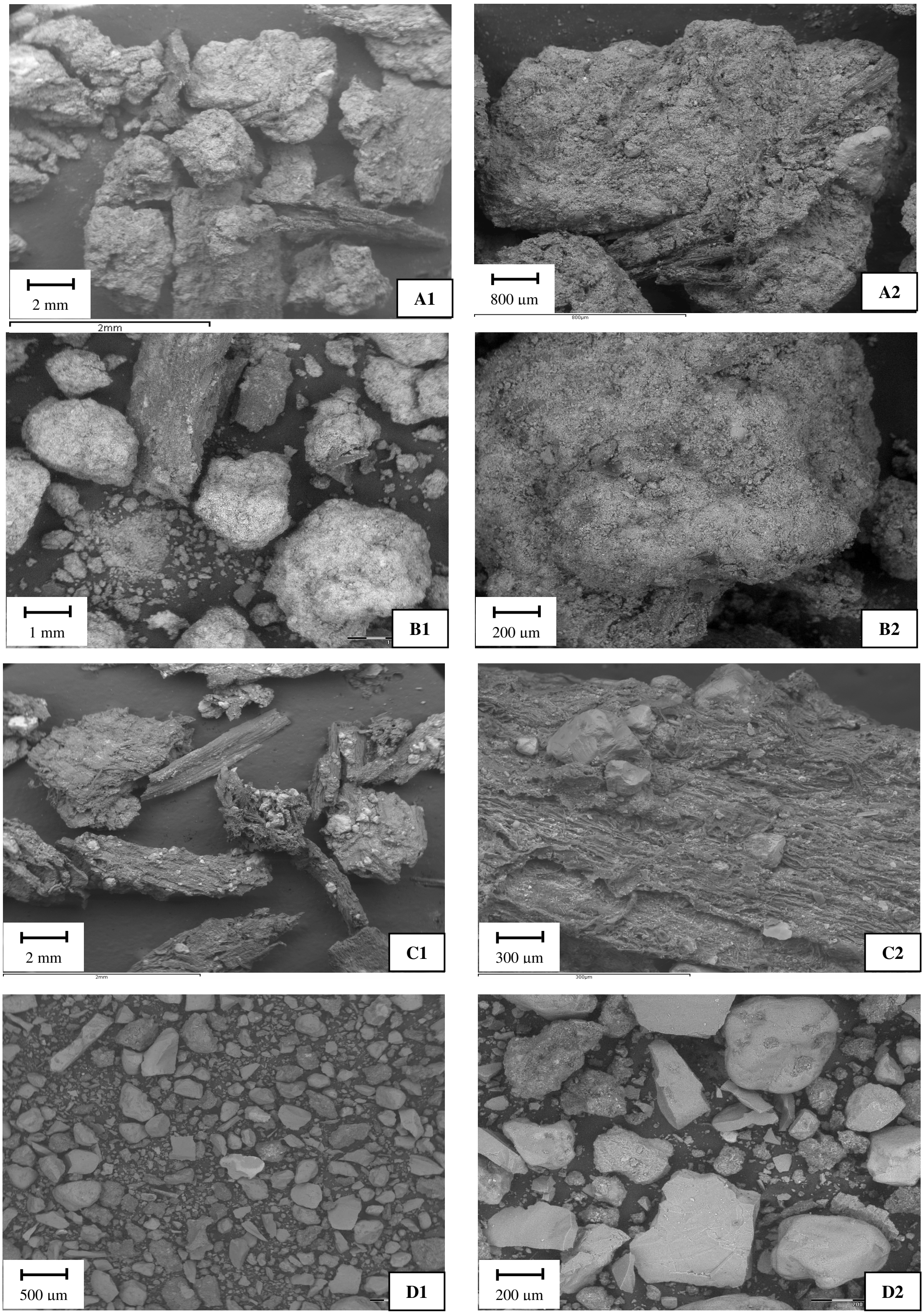


Fig. 4.31: Scanning electron micrographs of wood vermicompost and soil

A. 1*QR*:2LM+*EF*,
B. 1*QR*:3LM+*EF*,
C. 1*QR*:2HM+*EF*,
D. Soil as a reference

4.1.4. Thermal analysis of wood vermicompost

Thermogravimetric analysis (TGA) and different thermal analysis (DTA) is a type of testing that is performed on samples to determine changes in weight in relation to change in temperature. Such analysis relies on a high degree of precision in three measurements: weight, temperature, and temperature change. This technique provides information on the mass loss as a function of temperature. Figure 4.32 shows TG and DTA curves of *QR* wood vermicompost selected from first and second compost experiments. The selected wood compost samples are vermicompost produced from mixing *QR* wood with LM (Figure 4.32-B), *QR* wood mixed with HM (Figure 4.32-C) and *QR* wood mixed with LM and HM together (Figure 4.32-D). For more clarification the vermicompost samples were compared with a soil sample (Figure 4.32-A). The TG losses in air of the wood vermicompost and soil samples, together with the DTA, are reported in Figure 4.32 and the deduced thermal parameters of all the samples are summarized in Table 4.16.

The corresponding DTA curves show that the first step of mass loss is always an endothermic reaction. Most probably it originates from the dehydration of bound water. The first at around 105° C is due to free water. The second peak, between 100° C and 200° C, is due to loss of bound water as a consequence of OM dehydration. The amount of bound water increases with increasing OM content (FRIEDRICH et al., 1996, SMIDT & LECHNER, 2005). The TG loss curves showed the high differences between soil and vermicompost samples. Clearly, the TG curve of soil sample is classified to three mass transitions while the mass loss of vermicompost samples could be arranged as four mass regions. The data of TG curve show that up to 200° C the highest values of free and bound water was recorded to sample B (5.62 %) followed by D (4.47 %), C (3.51 %) and finally A sample(2.97 %). This trend reflects the effect of OM content of the studied samples, which it was the lowest in soil sample (Figure 4.32-A). Mass losses above 200° C are mainly connected with exothermic reactions due to combustion of the OM. The exothermic reaction process in soil sample (A) are in the range up to 550° C, which leads to 9.36 % mass loss (the OM loss in TG plots corresponds to the value obtained by loss on ignition method, 9.63 %). The last peak of soil are endothermic reaction and located around 600° C (between 550° C and 760° C) characterize the decarbonization of calcite ($CaCO_3$) with loss of CO_2 and may be attributable to a phase transition of quartz.

On the other side, the TG losses of vermicompost samples shows that there are four mass transitions located between 20° C and 800° C. Between 200 and 430° C, the weight loss in the vermicompost samples are 18.9, 10.26 and 20.68 % for sample B, C, and D respectively. This trend may be attributed to the decomposition of aliphatic structures, phenolic acids, mono and polysaccharides, and partly cellulose. Also at these temperatures, humic acids and lignin decomposed as OH and COOH groups were completely eliminated (FARES et al., 2005). Between 400 and 550° C the weight loss is due mainly to the decomposition of aromatic polycondensates with the lowest oxygen content and stable moieties (LOPEZ-CAPEL et al., 2005). The highest mass losses (8.46 %) recorded to the vermicompost produced from the mixture of wood and LM (B), while the lowest value (6.20 %) of mass loss was appeared in vermicompost of wood and HM (C). HM enhanced decomposition of wood and consequently decreasing the readily oxidizable organic forms compared to LM. As compost become more stable, products that burn within the range of temperatures 200-350° C disappear (SMIDT & LECHNER, 2005). Finally, the weight loss at temperatures higher than 550 ° C was associated with endothermic oxidation of refractory C as well as with the decomposition of both mineral and biogenic salts (BAFFI et al., 2007). Moreover, the mass loss in this transition may be attributed to the $CaCO_3$ decarboxylation (ALICE et al., 2008). The vermicompost produced from wood mixed by LM contain the highest amount of $CaCO_3$, which may be due to the high amount of calcite in LM. The highest value of calcite recorded to sample B (17.92 %) followed by sample D (10.53 %) and finally sample C (1.27 %).

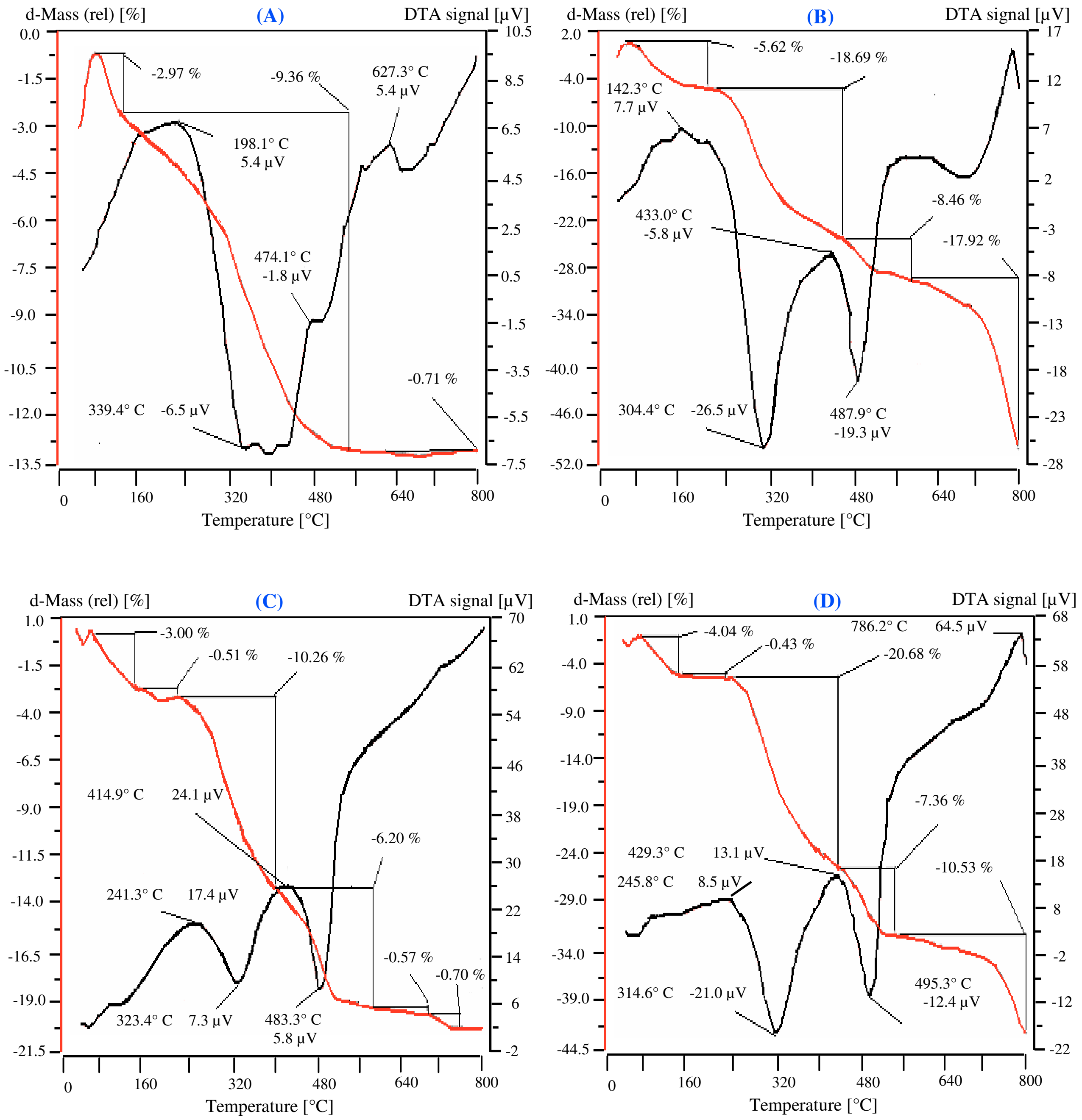


Fig. 4.32: TG (red color) and DTA (black color) curves of soil and vermicompost samples

(A) = soil, (B) = 1*QR*:3LM+*EF*, (C) = 1*QR*:2HM+*EF*, (D) = 1*QR*:1LM:1HM+*EF*)

Table4.16: Main thermogravimetric weight losses (% of total sample) which they occurred of vermicompost and soil samples

Samples / Mass loss	A	B	C	D
H_2O weight loss [%]	2.97	5.62	3.51	4.47
Total mass loss [%]	13.04	50.69	21.24	43.04

(A) = soil, (B) = 1*QR*:3LM+*EF*, (C) = 1*QR*:2HM+*EF*, (D) = 1*QR*:1LM:1HM+*EF*

Since sample B and D were richer in carbonates which were decomposed around 650° C, while sample A and C ashes were mainly composed by inorganic nutrients (N, P or S) which decomposed at higher temperature (SMIDT & LECHNER, 2005). As showed in Figure 4.32, the thermal transitions occurred at temperatures slightly above or down their respective mass transitions because of the inertia in the measurement system.

The results of DTA curves presented in Figure 4.32 showed the soil sample DTA curve which classified to three regions. The first is endothermic peak and located at maximum 198.1° C , the second is exothermic peak located between 200 and 550° C and finally the third peak was endothermic and located between 550 and 700° C . On the other hand, the simultaneous analysis of thermal transitions in air showed a similar pattern for all wood vermicompost samples: there were two exothermic peaks and two endothermic associated with mass transitions (DTA curves in Figure 4.32-B, C, D). The first peak was endothermic and at maximum 142.3, 241.3 and 245.8° C for sample B, C and D respectively. As shown previously the heat was consumed in this stage for dehydration of free and bound water. Differences in the intensity of endothermic peaks among the studied materials might be due to different amount of absorbed water. The second peak was exothermic and at 215.0 to 440.0° C, 205.0 to 400.0° C, and 216.0 to 434.6° C for sample B, C, and D respectively. This trend may be attributed to the decomposition of humic acid accumulated during composting processing and presence of aliphatic and non aromatic compounds (FARES et al., 2005; ALICE et al., 2008).

It was clear the vermicompost produced from wood mixed by HM gave the high values of generated temperature in due to high amount of humic acid, which it was demonstrated previously by the measurements of HA in wood vermicompost. The third peak are an intense sharp exothermic and located at maximum 487.9, 483.3, and 495.3° C for samples B, C, and D respectively. This indicates that more energy flows into the sample before the second followed stage of decomposition. This peak may be resulted from the decomposition of the accumulated fulvic acid (FARES et al., 2005). Also, the mass (thermal) transition, in the range of 415-600°C (475°C), may be due to the thermal breakdown of more aromatic moieties, either naturally occurring in the sample or resulting from molecular rearrangements (ALICE et al., 2008). The differences founded between vermicompost samples in this region could be explained to a different degree of maturity. Vermicompost produced from the mixture of wood and HM seems to be more mature and thermostable. Finally the last peak was endothermic and associated to a thermal transition at maximum 786.2° C, it was related with $CaCO_3$ decarboxylation; this peak is much more evident for vermicompost produced from wood and LM than vermicompost produced from wood and HM. This could be explained by high amount of $CaCO_3$ of LM compared to HM. Moreover, this may be due to thermal decomposition of the remaining lignin pyrolysis products (e.g. p-coumaryl, coniferyl, and sinapyl alcohols). Also, data in Table 4.16 showed the high differences of total mass loss of the studied samples. The highest value (50.69 %) was recorded to sample B followed by D (43.04 %), C (21.24) and finally A sample (13.04 %). This trend reflects the amount of OM and $CaCO_3$ in the studied samples.

Despite the temperature difference and despite the different natures and origins of the processed vermicompost products, the exothermic peaks of these materials seem to correspond to each other. The exothermic reactions mostly derive from organic matter oxidation, and that the heat evolved is roughly proportional to the amount of organic matter in the sample. The low differences between vermicompost samples in exothermic peaks may be due to different amounts of humic and fulvic acids. This was probably because of the presence different amounts of cation species such as Ca^{2+}, Ba^{2+}, and Fe^{3+} in vermicompost samples that usually reduce the thermal stability of humic acids. Consequently, it seems highly probable that these cation species caused shifting of the respective exothermic peaks toward lower temperatures. Also, the high amount of divalent and trivalent cations interact with carboxyl and phenolic hydroxyl groups causing a severe strain on the molecular structure of humic acid. As a result, metal–humic acid complexes become less stable against thermal decomposition (FARES et al., 2005). Finally, in comparison with soil sample the vermicompost samples were slightly less thermostable, when considering the first exothermic peak of vermicompost (ranged from 204 to 440° C) with the other in soil (210-550° C). It means the soil OM was more thermostable than vermicompost OM. This may be due to vermicompost contain higher amount of labile and soluble OM compared with that in soil. Also high amount of cations in vermicompost compared to soil may be affected the OM stability in this region. Nevertheless, the vermicompost samples seems to be more thermostable in the second exothermic reaction which reflects the high amount of fulvic acid and aromatics components, when compared with their counterparts in soil (FARES et al., 2005; ALICE et al., 2008). Also, the high thermal stability of wood vermicompost OM, probably increases its beneficial effects for a long time after added to the soil.

Effect of charcoal on vermicompost stability

In addition to the problem of reducing organic matter in the extreme and poor soil, most of soils are suffering from decreasing the degree of organic matter stability. Therefore, in this experiment we are trying to find a way to increase the degree of stability of vermicompost and consequently his organic matter stability. For this aim the vermicompost produced from the mixture of wood and HM was selected. Different application rate of charcoal as a source of carbon was added to the selected vermicompost. Data in Figure 4.33 showed TG and DTA curves of vermicompost untreated with charcoal (A) and the other samples treated with charcoal (3.0 % (B), 6.0 % (C), and 12.5 % (D)). The TG loss curves show that there are four mass transitions located between 20° C and 800° C.

The first peak located at maximum 241.3, 228.7, 226.5 and 220.3° C for sample (A), (B), (C), and (D) respectively. This is due free and pounded water and characterized as endothermic reaction. Increase amount of charcoal resulted in decreased thermal stability of absorbed water, the thermal value was observed in the treatments free from charcoal. The mass losses in this region are similar in the samples treated with charcoal (from 5.01 to 5.19 %) but it was higher than control.

The second thermal transitions are exothermic reaction and also no differences between the control and the vermicompost treated with charcoal (Figure 4.33). It means addition of charcoal had no effect on the degree of thermal stability of OM in this region. Increasing application of charcoal lead to increase amount of combustible OM as showed in TG loss curve. The lowest values (10.26 %) of weight loss recorded to the control while the highest mass loss (11.67 %) observed in the treatments treated with 12.5 % charcoal.

The third transition are exothermic peak and located at maximum 483.3, 492.6, 495.3, and 498.6° C for sample (A), (B), (C), and (D) respectively. This trend reflects the slightly increasing of thermal stability of OM due to increased addition rate of charcoal. Also, total mass losses in this transition was increased recorded the highest value (21.34 %) to the vermicompost treated with the highest amount of charcoal (12.5 %).

The last thermal transition was endothermic reaction and recorded for the loss of $CaCO_3$ and thermal decomposition of lignin pyrolysis products. The amount of $CaCO_3$ lost in this stage did not give stable direction as a result of adding charcoal. Generally, it can conclude that add charcoal to the vermicompost had no effect on the degree of OM thermal stability, with the exception of a slight increase in the second exothermic reaction. Moreover, the remarkable effect of increased addition rate of charcoal was increasing amount of mass lost in each thermal transition. Therefore it is necessary to search for another way to be relied upon to increase the degree of stability of organic matter.

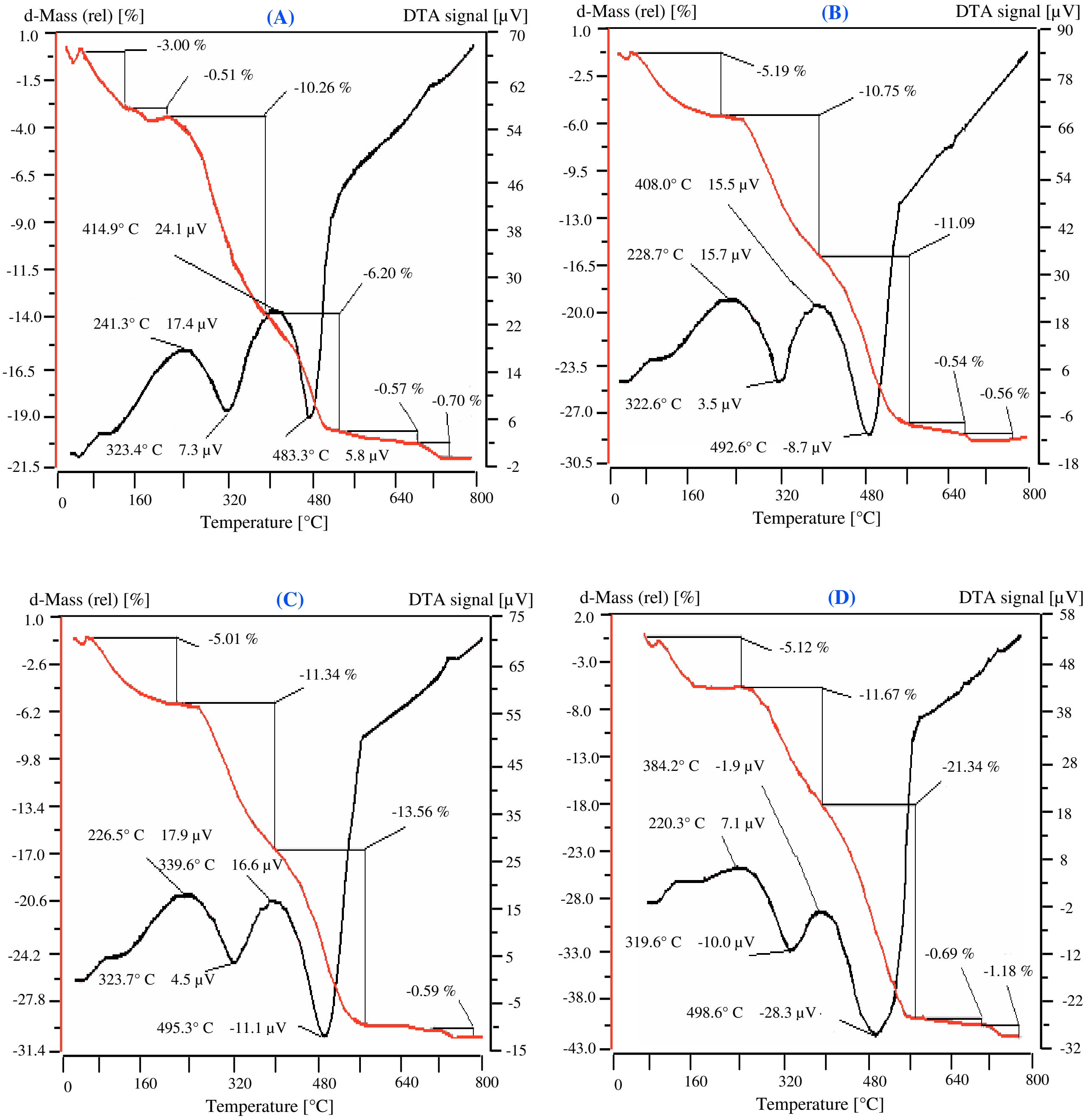


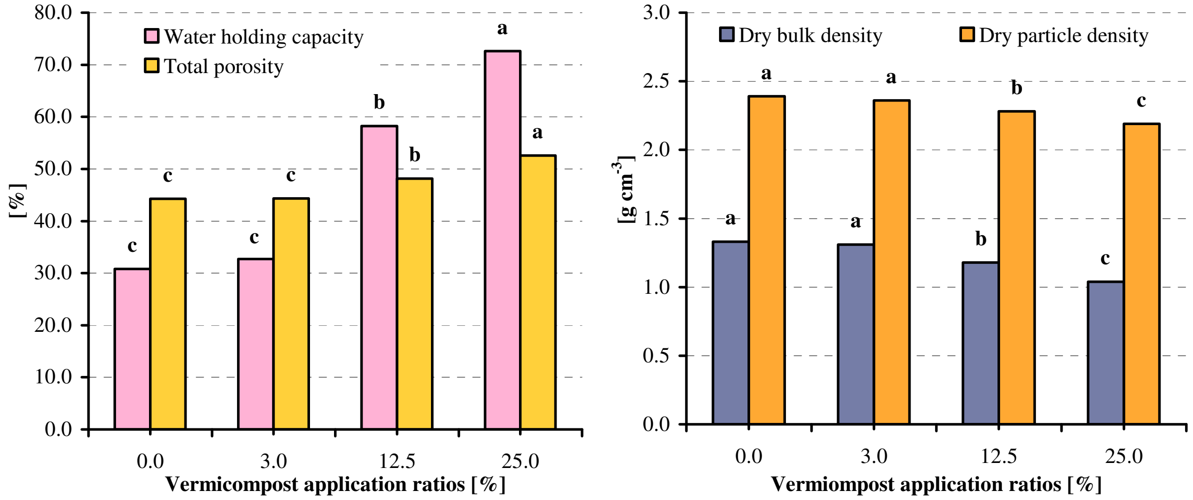
Fig. 4.33: TG (red color) and DTA (black) curves of vermicompost mixed with 0.0 charcoal (A), 3.0 % charcoal (B), 6.0 % charcoal (C), and 12.5 % charcoal (D)

4.2. Plant experiments

4.2.1. Greenhouse plant experiment

4.2.1.1. Effect of vermicompost on soil physical properties

In this experiment, the *QR* wood vermicompost produced from first compost experiment was used to study its effects and ability to reclamation and revegetation the tertiary soil that has been ravaged during coal mining operations. Effects of vermicompost on soil physical attributes are depicted in Figure 4.34 (Table A.31). The data indicate that, different application rates of vermicompost affected on different soil physical properties. The soil water holding capacity (WHC, [%]) and total porosity (TP, [%]) were improved by the use of vermicompost. The WHC and TP increased significantly as the vermicompost rates increased, regardless of 3.0 % application rate. The treatments can be arranged as the 25.0 % vermicompost treatment was the highest followed by 12.50, 3.00 % and finally control. In addition, the highest percentage of WHC (72.60 %) and TP (52.59 %) were found with 25.0 % vermicompost application rate, while the lowest value of 30.83 and 44.29 % respectively was observed in the control. It was attributed to their higher pore space, low bulk density and favorable soil structure. These trends can be explained as follows; when the compost is mixed with soils it binds to the soil particles forming larger particles that now have larger air spaces between them. Moreover, the greater porosity in the tertiary soil treated with vermicompost was due to an increase in the amount of rounded prose (MARINARI et al., 2000). RASOOL et al. (2008) reported that the increase in porosity has been attributed to increased number of pores in the 30 - 50 µm and 50 - 500 size ranges and a decrease in number of pores greater than 500 µm. Vermicompost organic substances can hold up to 20 times its weight in water, which leads to increase the soil's water holding capacity (AGGELIDES & LONDRA, 2000).



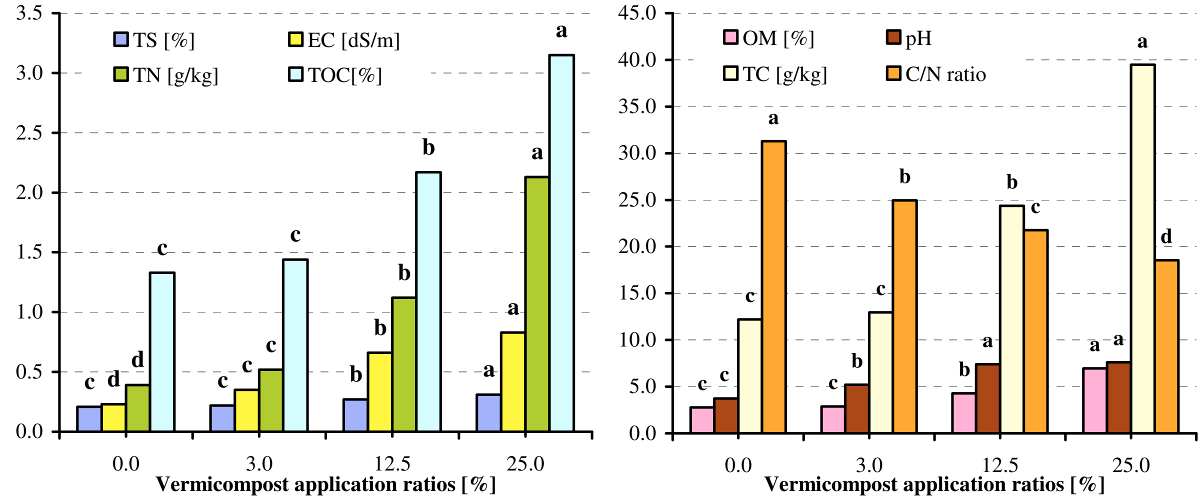
Columns of the same category labeled with different letters are significantly different at 0.05 level of probability

Fig. 4.34: Soil physical properties as affected by different application rates of vermicompost (data are means for three replications)

Also, the data showed that tertiary sediments amended with vermicompost had significantly lower dry soil bulk (BD) and dry particle density (PD) in comparison to control treatment (Fig. 4.34). Increased rates of vermicompost reduced significantly soil bulk and particle density. The 3.00 % vermicompost treatment did not appear any significant differences, but it was higher than control treatment. The lowest values of BD (1.04 g cm^{-3}) and PD (2.19 g cm^{-3}) were recorded to 25.0 % rate of vermicompost, whereas the highest value was noted in control treatment (1.33 and 2.39 g cm^{-3} for BD and PD respectively). Vermicompost addition caused a significant decrease of BD and PD due to the more porosity added to the soil (RASOOL et al., 2008). The other reason may be the composted organic matter improves soil aggregation and structure by reducing the potential for soil compaction (AGGELIDES & LONDRA, 2000; WANAS & OMRAN, 2006). High OM content of vermicompost decreased BD and PD of soil. OM, which weighs much less than an equal volume of mineral solids, which consequently decrease the DB and PD of soils (AGGELIDES & LONDRA, 2000).

4.2.1.2. Effect of vermicompost on soil chemical properties

Application of different rates of vermicompost had significantly influenced the tertiary soil chemical properties. The data presented in Figure 4.35 (Table A.32) showed the different application rates of vermicompost had positive effects on different soil chemical properties, with the exception of the C/N ratio, which decreased with the increase in vermicompost application rate. The electrical conductivity (EC) in vermicompost was 3.19 [dS m^{-1}] (mS.cm^{-1}). The soil amended with vermicompost had significantly higher EC than the untreated soils (Figure 4.35). The soil EC increased with increasing an application rate of vermicompost in soil as reported by ATIYEH et al. (2001). The EC of vermicompost depends on the raw materials used for vermicomposting and their ion concentration (ATIYEH et al., 2002). Also, this trend may be due to the high amount of nutrients in the applied vermicompost. The addition of vermicompost in soil change soil pH (Fig. 4.35). The highest (7.61) and lowest (4.50) pH values were observed at the rate of 25.0 and 0.0 % vermicompost, respectively. There is no conspicuously significant difference in pH value among of 25.0 and 12.5 % vermicompost treatments; however the 25.0 % was the highest. This trend may be the result of the high base content in the vermicompost and its large capacity to absorb free protons (H^+) in the soils, this result is similar to that reported by COX et al. (2001).



Columns of the same category labeled with different letters are significantly different at 0.05 level of probability

Fig. 4.35: Soil chemical properties as affected by different application rates of vermicompost (data are means for three replications)

In addition, data in Figure (4.35) show that, the amounts of total organic carbon (TOC), organic matter (OM), total carbon (TC) and total sulphur (TS) increased significantly with an increase in vermicompost application rate, with exception of the 3.0 % addition which was insignificant compared to control treatment. With different application rates of vermicompost the total nitrogen (TN) increased significantly, while the C:N ratio gave contrasting values when increasing vermicompost application rate. The increases of these parameters may be due to their high proportion in vermicompost compared to soil. Particularly, vermicompost might have produced more residual N in soil than those in control pots. The marked decrease in total N in soils without vermicompost application in comparison with vermicompost treated soils may have been due to larger amounts of total C and N in wood vermicompost that could have provided a larger source of N for mineralization (ARANCON et al., 2007; RASOOL et al., 2008). It is expected that the vermicompost will incorporate more OM and OC to the soil, because of the greater OM stability in the vermicompost (RENATO et al., 2003).

Effect of vermicompost on cation exchange capacity and total exchangeable acidity

The vermicompost with a relatively high content of humus-like compounds, active micro organisms and enzymes, greatly contribute to the enhancement of the biochemical fertility of degraded soils. The data presented in Table 4.17 showed the high clear effect of wood vermicompost on cation exchange capacity and total exchangeable acidity. The exchangeable bases are increased significantly with the increase of vermicompost application rate (with the exception of K^+ and Na^+ at an addition rate 3.0 %). The highest value of the exchangeable bases was recorded for Ca^{++} followed by Mg^{++}, K^+, and Na^+. The highest amount of exchangeable cations (5.90, 2.06, 1.44, and 1.42 cmol kg^{-1} for Ca^{++}, Mg^{++}, K^+, and Na^+ respectively) were associated with the application of 25.0% vermicompost. While the lowest amount of exchangeable cations (0.73, 0.69, 0.62, and 0.59 cmol kg^{-1} for Ca^{++}, Mg^{++}, K^+, and Na^+ respectively) were recorded in the control. Increases amount of these bases may be due to their high proportion in vermicompost compared to the untreated soil. The summation of exchangeable bases (TEB) shows the same trend of exchangeable bases value, it was increased significantly with the increasing of vermicompost application rates (RENATO et al., 2003).

Table 4.17: Cation exchange capacity, total exchangeable acidity and saturation percentage in soil with different application rates of vermicompost (data are means for three replications)

VAR[a]	Exchangeable cations				TEB	TEA	ECEC	PCEC	BS
	Ca^{++}	Mg^{++}	K^+	Na^+					
[%]	[cmol kg^{-1}]				[cmol kg^{-1}]				[%]
0.0	0.73 d	0.69 d	0.62 c	0.59 c	2.64 d	1.52 a	4.16 d	4.43 d	63.46 d
3.0	1.08 c	0.89 c	0.68 c	0.62 c	3.27 c	1.36 b	4.63 c	5.66 c	70.63 c
12.5	3.85 b	1.17 b	0.97 b	0.91 b	6.90 b	1.16 c	8.06 b	11.34 b	85.61 b
25.0	5.90 a	2.06 a	1.44 a	1.42 a	10.81 a	1.02 d	11.83 a	15.37 a	91.38 a
$LSD_{0.05}$	0.19	0.08	0.09	0.07	0.29	0.12	0.29	0.82	4.21

Mean of the same category followed by different letters are significantly different at 0.05 level of probability
[a] = Vermicompost application ratios

In addition, the data in Table (4.17) show that increasing vermicompost application rate led to decreased total exchangeable acidity (TEA). The TEA values were negligible compared to TEB. The data indicate that, the highest value (1.52 cmol kg^{-1}) of TEA was occurred in the control, while the lowest value (1.02 cmol kg^{-1}) was founded in the soil treated with 25.0 % vermicompost. This trend may be due to the reaction of the compost with the exchangeable acids reducing their activity. The effective and potential cation exchange capacity (ECEC and PCEC) and in consequence the base saturation percentage (BS) were significantly increased with the increase of vermicompost application rate. The soil treated with 25.0 % vermicompost showed the highest values of 11.83, 15.37 cmol kg^{-1}, and 91.38 % for ECEC, PCEC, and BS respectively, while the lowest values were recorded to the untreated soil (Table 4.17). This trend could be explained by vermicompost characterized by the greater production of functional groups, which are responsible of surface charges. The other reason may be the high proportion of fine particle and OM in vermicompost, thereby increasing the number of exchange sites for mineral nutrients (McCONNELL et al., 1994; PANDEY & SHUKLA, 2006).

Effect of vermicompost on soil acid-base buffering capacity

Soil acid and base buffering capacities can be expressed by the slope of buffer curves, according to the algebraic equation (Eq. 4.1), where x_2 and x_1 are the volume (ml) 16 and zero (100 ml dist water) respectively of HCl or NaOH added to sample, y_2 and y_1 are the pH of sample after adding 16 and zero ml respectively of HCl or NaOH.

$$Slope = (y_2 - y_1)/(x_2 - x_1) \qquad \text{(Eq. 4.1)}$$

The data illustrated in Figure (4.36) and the values of the curve slopes (buffering capacity) in Table (A.33) show that, an increase in the independent HCl and NaOH factor caused a decrease and increase in the dependent factor (pH) respectively. Generally, rates of change with the addition of acid were lower than with the addition of alkali, due to the presence of a high proportion of carbon in the soil (Table 3.5). In the present work, the experimental soil (control) showed low resistance to alkalization and acidification; the addition of an alkali (NaOH) caused pH changes which varied between 4.23 and 10.13 and on the addition of an acidifying agent (HCl) the pH changed from 4.23 to 2.24. Similarly, considerable changes in the curve slopes were recorded in the soil treated with 3.0 % vermicompost. The addition of HCl and NaOH caused a 1.60-unit pH decrease and 5.45-unit pH increase respectively. On the other hand, the addition of vermicompost increased tertiary soil resistance to change in pH, the highest resistance was recorded for the treatments with higher addition rates of vermicompost (12.5 and 25.0 %). The difference between the impact of 12.5 and 25.0 % rate of vermicompost, expressed by small area between the two curves, was very little. Treatments with 12.5 and 25.0 % vermicompost application rate exhibited notable resistance to acid impact, and a greater amount of acid (up to 16 cm^3) caused only a slight pH change (up to 1.14 and 0.83 pH units respectively).

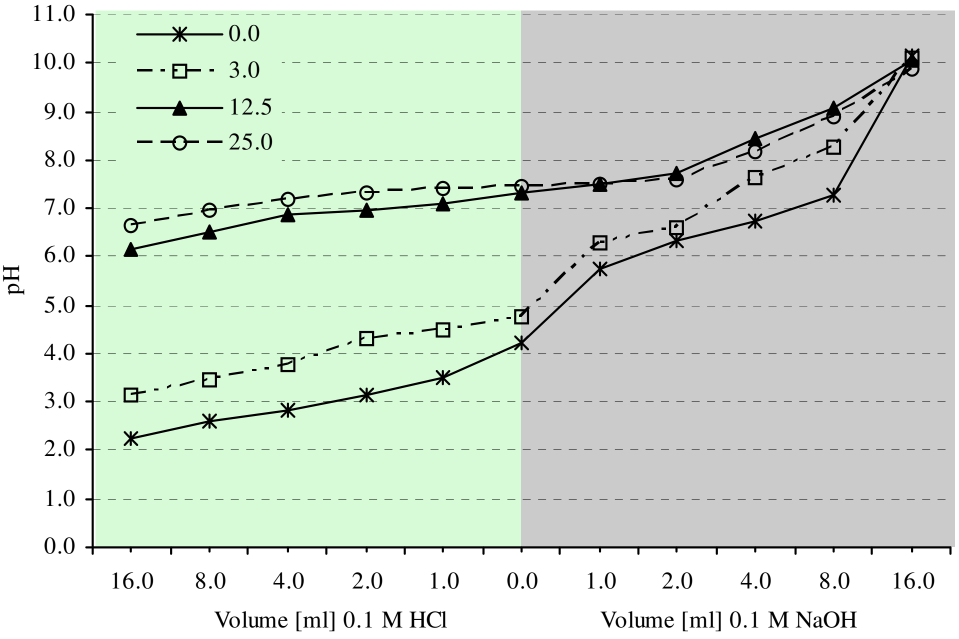


Fig. 4.36: Effect of base (NaOH) and acid (HCl) additions on changes in buffering capacities of tertiary soil treated with vermicompost (data are means for three replications)

When considering the data in Figure 4.36 (Table A.33), it can be seen that there is an inverse relationship between the curve slope and the soil resistance to change in pH, where the decrease in slope value means increasing soil resistance. The data show that, the highest soil resistance (lowest slope) was in tertiary sediments treated with 25.0 % vermicompost, it was +0.16 and -0.05 after adding an alkali and acid solution respectively. While the lowest soil resistance (highest slope) was recorded in the control treatment (+0.31 and -0.10 after adding NaOH and HCl respectively). The high resistance of these treatments may be due to the high organic carbon content and the presence of carbonates in vermicompost which act as a special “sink” for acid protons. Moreover, the addition of vermicompost led to increased soil resistance to change in pH by increasing the total surface available for cation exchange sites (COX et al., 2001). Similar curve slopes were reported by RACZUK (2001) and DIATTA (2006).

Effect of vermicompost on available soil macro and micro nutrients

The data in Table (4.18) shows the available element content (mg kg^{-1}) of the experimental soils as affected by different application rates of vermicompost [%]. These data reveal that, available value of N, P, K, Ca, Mg, Cu, Zn and Mn in the soil treated with vermicompost was higher than their values in untreated soil. These nutrients were increased significantly after application of 12.5 and 25.0 % rates of vermicompost. There was no differing significantly observed in the values of these nutrients under addition of 3.0 % vermicompost compared to control. These effects may have been caused by the high content of these elements in the vermicompost. Moreover, the available nutrient status of soil was greatly enhanced by the application of vermicompost (ARANCON et al., 2004; ASCIUTTO et al., 2006). Vermicompost increased the pH which effects nutrient availability (most elements prefer the neutral pH). In contrast, iron (Fe) was recorded in higher concentrations in the control than in other treatments. The value of Fe decreased significantly with the increasing of vermicompost application rates. These results may be due to the fact that Fe is mobile under acid conditions, and by raising the pH with vermicompost its bioavailability is reduced (IM-ERB et al., 2004).

Table 4.18: Available macro and micro nutrients content in soil as affected by different application rates of vermicompost (data are means for three replications)

VAR^{a}	Macronutrients					Micronutrients			
	KCl-N	Bray^{1}-P	K	Ca	Mg	Fe	Cu	Zn	Mn
[%]	[mg kg^{-1}]		EDTA-[mg kg^{-1}]			EDTA-[mg kg^{-1}]			
0.0	14.05 c	7.32 c	186.84 c	315.46 c	255.52 c	285.17 a	0.49 c	0.84 c	1.05 c
3.0	27.66 c	8.11 c	190.20 c	322.50 c	264.37 c	251.53 b	0.52 c	1.30 c	1.58 c
12.5	394.69 b	11.61 b	274.12 b	630.86 b	322.56 b	147.11 c	0.82 b	3.31 b	23.43 b
25.0	653.25 a	16.35 a	387.15 a	820.73 a	394.60 a	145.43 c	1.28 a	7.03 a	44.51 a
LSD $_{0.05}$	24.85	0.83	10.96	22.73	9.46	4.65	0.35	0.64	1.25

Mean of the same category followed by different letters are significantly different at 0.05 level of probability.
^{a} = Vermicompost application ratios

Also the results revealed that the soil Fe concentration did not differ significantly between 12.5 and 25.0 % treatments. This may be due to the slightly increasing in pH after addition of 25.0 % vermicompost (Table A.32). More deeply, the high significant improvement of available N as affected by the addition of vermicompost may be resulted from its high mineralization rate of total nitrogen in vermicompost. The soil treated with vermicompost at rate of 25.0 % had significantly more available P (16.35 mg kg^{-1}) as compared to control pots (7.32 mg kg^{-1}). The enhancement of phosphatase activity resulted in greater mineralization. Moreover, increased available P may be resulted from the increase of soil pH caused from application of vermicompost (ARANCON et al., 2004, 2007). The increase of soil organic matter after application of vermicompost may be resulted in decrease K fixation and subsequent increase K availability. Also, the highest increase of Ca was calculated 820.73 and 630.86 mg kg^{-1} for the application of 25.0 and 12.5 %

vermicompost respectively (Table 4.18). This could explained by vermicompost contains most nutrients in plant available forms such as phosphates, exchangeable calcium and soluble potassium (RASOOL et al., 2008). High content of extracted Mn, Zn, and Cu with EDTA in the soil treated with vermicompost can be due to the dissolution of these nutrients precipitates (carbonates, hydroxides and phosphate) caused by microbial activity that changes soil pH and gaseous composition (RASOOL et al., 2008).

4.2.1.3. Effect of vermicompost on planting properties

Chemical composition of grass (straw)

Diagnosis of the symptoms of nutrient deficiency in *RSM* grass grown in acid soil with application of various doses of wood vermicompost was confirmed by analysis of the complete straw (aerial part) (Table 4.19). The data indicate that, the uptake of macronutrients (N, P, K, Ca, and Mg) did not differ significantly at addition rates of 3.0 and 25.0% vermicompost compared with control and 12.5% vermicompost respectively. Under different studied treatments the straw macronutrients content [g kg^{-1}] can be arranged as N was the highest followed by K, Ca, P, and Mg. The highest N content was found at application rate of 25.0% vermicompost followed by 12.5 %, 3.0 %, and control at amounts of 36.99, 33.59, 10.90, and 6.69 g kg^{-1} respectively. According to MENGEL and KIRKBY (1987), NH_4-N uptake takes place most effectively in a neutral medium and decreases as the pH falls.

Phosphorus (P) levels were found to differ among treatments, with the highest concentration observed in the treatment of 25.0 % vermicompost (4.48 g kg^{-1}). Increasing uptake of P in the tertiary soils treated with vermicompost may be due to orthophosphates in soil solution can react with the oxides and hydroxides of aluminum, iron and manganese to form water insoluble compounds when soil pH is ≤ 5 (ZOU et al., 2007). So, the application of vermicompost increased soil pH, and consequently increased the availability of P. Moreover available P found with a high quantity in vermicompost.

Potassium levels (K) were found to be higher than the control with the highest concentration observed in treatment containing 25.0% vermicompost (13.72 g kg^{-1}). This trend was due to high amount of available K in vermicompost compared to soil (Table 4.18). Similarly, grass grown in the media with 25.0 % vermicompost had significantly higher Ca and Mg concentrations (7.15 and 3.13 g kg^{-1} respectively) compared to the control. This could be also explained by addition of vermicompost to soil increased nutrient contents in the substrate and gave higher concentrations of soluble Ca and Mg (RENATO et al., 2003; CHAMANI et al., 2008).

The data presented in Table (4.19) shows the *RSM* straw micronutrient content [mg kg^{-1}]. Analysis of the concentrations of micronutrients in the aerial part (straw) showed the iron (Fe) was the highest followed by manganese (Mn), zinc (Zn), and finally copper (Cu). The Fe content of plant tissues decreased significantly with increasing vermicompost in the base media compared to the control. The highest value (439.21 mg kg^{-1}) was found in the control, while the lowest value (316.70 mg kg^{-1}) recorded to the soil treated with 25.0 % vermicompost. No significant difference in Fe was found between plants grown in the media with 12.5 and 25.0 % vermicompost. This trend of Fe content in plant tissues (straw) may be due to the addition of vermicompost increased pH and consequently decreased the availability of Fe (MENGEL & KIRKBY, 1987; ZOU et al., 2007). No significant differences in Cu concentration were found between plants grown in different studied treatments. However, there was a slightly higher concentrations observed to the grass grown in the soil treated with 25.0 % vermicompost (10.63 mg kg^{-1}). Also, the data in Table (4.19) indicated the Zn concentration of plant tissues increased significantly in the soil treated with 12.5 and 25.0 % vermicompost compared to control. But the effect was not significant for the plants grown in 3.0 % vermicompost (MENGEL & KIRKBY, 1987).

Table 4.19: Macro and micro nutrients content of plants (straw) as affected by different application rates of vermicompost (data are means for three replications)

VAR[a]	Macronutrients					Micronutrients			
	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn
[%]	[g kg^{-1}]					[mg kg^{-1}]			
0.0	6.69 b	0.68 b	1.87 b	0.68 b	0.63 b	439.21 a	10.32 a	31.77 b	105.50 b
3.0	10.90 b	0.93 b	3.75 b	1.34 b	0.99 b	410.63 b	10.50 a	32.18 b	111.03 b
12.5	33.59 a	3.97 a	12.56 a	6.72 a	2.79 a	328.10 c	10.50 a	62.91 a	125.76 a
25.0	36.99 a	4.48 a	13.72 a	7.15 a	3.13 a	316.70 c	10.63 a	67.79 a	126.25 a
LSD $_{0.05}$	4.63	1.12	3.79	2.26	0.53	12.56	0.50	7.49	8.35

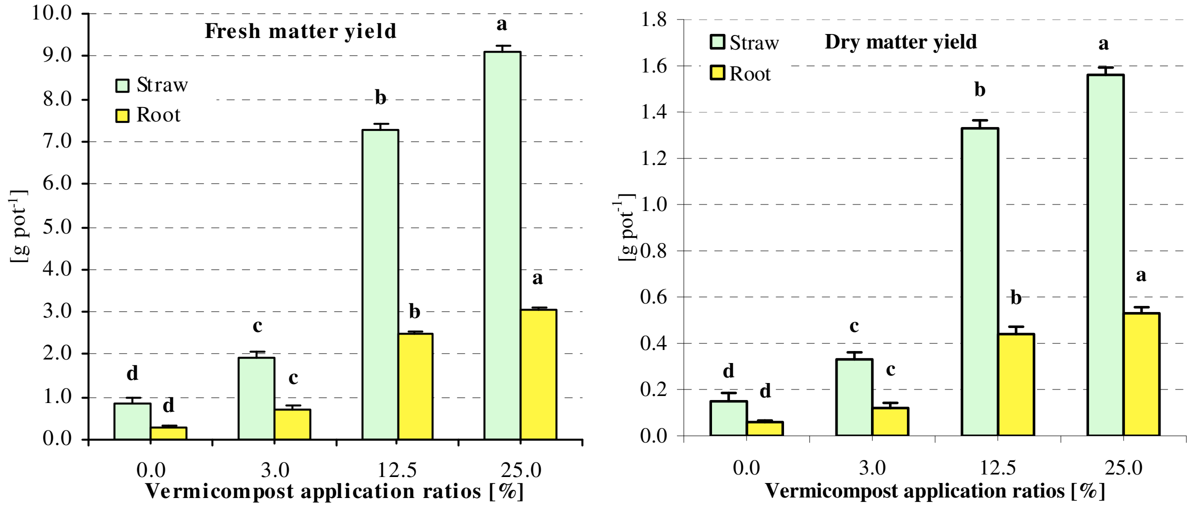
Mean of the same category followed by different letters are significantly different at 0.05 level of probability
[a] = Vermicompost application ratios

Similarly, Addition of vermicompost to the studied soil (tertiary sand) tended to increase concentration of Mn in *RSM* grass (Table 4.19). The high value of Mn (126.25 mg kg^{-1}) was appeared in plant grown in the soil with 25.0 % vermicompost and the low value (105.50 mg kg^{-1}) noticed in the grass of control. However, no significant difference in Mn concentration was found between plants grown in the 3.0 % vermicompost amended media and the control. In normal plants Mn concentration is usually between 40-120 mg kg^{-1} (MENGEL & KIRKBY, 1987).

Normally the uptake of various plant nutrients depends upon pH, and nutrients are taken up at a higher rate in slightly acidic conditions. However, in some cases, ion competition, antagonism, or synergism among or between ions may occur, resulting in unusual uptake patterns. The absorption of cations is a more or less nonspecific process, depending mainly on the concentration of cation species in the nutrient medium (MENGEL & KIRKBY, 1987). Therefore, it can suggest that the application of vermicompost increased plant uptakes of micronutrients (except Fe). This could be explained by vermicompost contain micronutrients in available form and high quantity which encourages the plant to uptake his requirements. The other reason may be the incorporation of vermicompost in the studied soil had a positive effect on soil pH which consequently affects the availability of micronutrients (RENATO et al., 2003; IM-ERB et al., 2004; CHAMANI et al., 2008; SUTHAR, 2009).

Fresh and dry matter yield

There was statistically significant difference among treatments for plant yield parameters. The results in Tables (A.34 and A.35) and illustrated by figures (4.37 and 4.38) show that, plants seem to respond positively to the application of wood vermicompost. Under different application rates of vermicompost, the fresh and dry weight (g pot^{-1}) for both straw and roots were increased significantly compared to the control. The application of 25.0 % vermicompost gave the highest fresh yield of straw (9.12 g pot^{-1}) and roots (3.05 g pot^{-1}), while the lowest values were recorded to the control treatment (RASOOL et al., 2008). The lowest fresh matter yield was 0.85 and 0.30 [g pot^{-1}] recorded to the control for straw and root respectively. Similarly, the maximum dry weight of straw and root were observed for the grass grown on the soil treated with 25.0% vermicompost. It was 1.56 and 0.53 [g pot^{-1}] respectively. Grasses grown in the control treatment showed the lowest values of dry matter yield for both straw and root. It was 0.15 and 0.06 [g pot^{-1}] for straw and root respectively. In brief, the effect of applied vermicompost on both straw and root yield can be arrange as the plant grown in the soil treated with 25.0 % vermicompost is the highest followed by 12.5, 3.0 % and control. This trend could be explained by wood vermicompost is rich in all necessary nutrients for plant growth. Vermicompost enhanced soil physiochemical and microbiological properties and correspondingly plant growth parameters (CHAMANI et al., 2008; SUTHAR, 2009). N, P, K deficiency may be the reasons for reduced the grass yield in the soil untreated with vermicompost. N is required for form amino acids, amino enzymes, nucleic acids, chlorophyll, alkaloids, and purine bases. P is a component of certain enzymes and proteins, adenosine triphosphate (ATP), ribonucleic acids (RNA), deoxyribonucleic acids (DNA) and phytin. K is required in the accumulation and translocation of carbohydrates (MENGEL & KIRKBY, 1987).



Columns of the same category labeled with different letters are significantly different at 0.05 level of probability

Fig. 4.37: Fresh and dry matter yield of both straw and roots as affected by different application rates of vermicompost (data are means for three replications)

Relative to fresh and dry weights in the control treatment, a high relative increase (RE, %) of fresh and dry weight for both straw and roots was recorded in the 25.0 % followed by 12.5 % and finally the 3.0 % vermicompost (Tables A.34 and A.35). The increments of fresh straw weight due to the application of vermicompost were 128.24, 754.12 and 972.94 % for the 3.0, 12.5, and 25.0 % vermicompost treatments respectively. Also, the high relative increasing value (916.67 %) of fresh root weight was recorded to the plants grown on the treatment with 25.0% vermicompost, while the low value (140.0 %) was observed in the control treatment. This positive trend may be due to the effect of highly available macro and micro nutrients presented in wood vermicompost. Increase amount of available nutrients by increasing addition rates of vermicompost, should be reflected by increased nutrients absorbed by plant and consequently the plant biomass yield (IM-ERB et al., 2004; CHAMANI et al., 2008; SUTHAR, 2009). The presence of nutrients in the optimum level will affect the metabolisms processes within the plant and therefore the plant biomass (MENGEL & KIRKBY, 1987). Also, the high relative increasing in the soil treated with vermicompost may by due to the very small biomass yield of the plants grown in the control treatment. The untreated soil was very poor in the necessary nutrients for plants (except Fe). Iron (Fe) founded with a very high available amount, this amount may be toxic for seed germination and plant growth. To much Fe without adding enough P can cause a P-deficiency. All these reasons affected on plant biomass yield of grass grown in the control, consequently the high relative increasing for the soils treated with vermicompost.

Also, the agronomic efficiency (AE) of fresh and dry weight for both straw and roots was recorded in Tables (Tables A.34 and A.35). When considering the mean values, each unit of vermicompost at an application rate 12.5 % had a greater efficiency of the yield compared to the other application rates. The data indicates the plant grown in the soil treated with 12.5 %

vermicompost gave the high values of fresh yield for both straw (0.51) and root (0.18). It means that each unit of vermicompost in this treatment gave the highest efficiency on the plant straw biomass, compared to 25.0 and 3.0 % vermicompost. At 25.0 % dose of vermicompost each unit of vermicompost increased the fresh weight of straw by 0.33 while this value was 0.36 for plant grown on 3.0 % vermicompost. This trend means each vermicompost unit in 3.0 % vermicompost treatment gave higher straw biomass weight than each vermicompost unit in 25.0 % treatment. Also the same trend of agronomic efficiency was noted in root biomass. Similarly, the high agronomic efficiency of wood vermicompost on dray weight yield was recorded to the plants grown on 12.5 % vermicompost (0.08 and 0.03 for straw and root respectively). Plants grown in the soil treated with 3.0 and 25.0 % vermicompost gave the same value of agronomic efficiency. It was 0.06 and 0.02 for straw and root respectively. It can suggest that 3.0 % addition rate of vermicompost did not enough for the plant requirements, in the same time the addition of 25.0 % vermicompost is more, and finally the rate of 12.5 % vermicompost may be the best fertilization rate in the reclaimed soil.

Plant height, number and germination rate

As presented in Table 4.20 and Figure 4.38, a significant difference in plant growth parameters: plant height, number of plants and germination rate was among the treatments. These parameters were recorded to the grass at the end of experiment (after 42 days). The application of 25.0% vermicompost gave the highest value of plant height (25.20 cm) followed by 12.5 % (21.90 cm), 3.0 % (14.40 cm) and finally the control (6.20 cm). The number of plants per pot was increased significantly with increasing the application rate of wood vermicompost. The maximum (428.00 plants pot^{-1}) number of plants was observed after addition rate of 25.0 % vermicompost. The minimum number of plants was noted in the untreated soil (74.00 plants pot^{-1}). Clearly, the data in Table (4.20) showed the high positive effect of applied vermicompost on seeds germination rate. The high value (94.90 %) was appeared in the soil treated with 25.0 % vermicompost, while the lowest value (16.41 %) was noted in the control. Also there was a high significant differences in germination rate were found between the studied treatments. This may have been the result of unfavorable conditions for growth in the control treatment compared to the vermicompost treatments.

Moreover, Figure 4.38 showed the high positive impact of wood vermicompost on plant vitality and growth. From right to left it seems the plant vitality, leaf length and wide were increased. Also the green color in plants was increased with increasing addition rate of vermicompost. The grass grown on control and 3.0 % vermicompost treatments was more yellow from lake of chlorophyll, while the other grown on soil treated with 12.5 and 25.0 % vermicompost was greener. This may be due to the high available amounts of N and P in the used vermicompost (MENGEL & KIRKBY, 1987). Yellow color in the control treatment may be due to high available Fe, which affected the absorption of N and P. Fe has a tendency of reacting with many nutrients, and will cause nutrient lockup to occur. Relatively, increased addition rates of vermicompost caused to increase plant strength. The plants grown with 25.0 % vermicompost seem to be stronger than the others. Also this behavior is due to the high responsive of plants to different addition rates of vermicompost. Especially the studied soil is very poor in the ingredients and growth success factors.

Table 4.20: Plant height, number and germination rate of RSM grass grown on soil treated with wood vermicompost (data are means for three replications)

Vermicompost application ratio [%]	Height [cm]	Number [plants pot^{-1}]	Germination rate [%]
0.0	6.20 d	74.00 d	16.41 d
3.0	14.40 c	255.00 c	56.54 c
12.5	21.90 b	364.00 b	80.71 b
25.0	25.20 a	428.00 a	94.90 a
LSD $_{0.05}$	2.50	15.63	20.04

Mean of the same category followed by different letters are significantly different at 0.05 level of probability

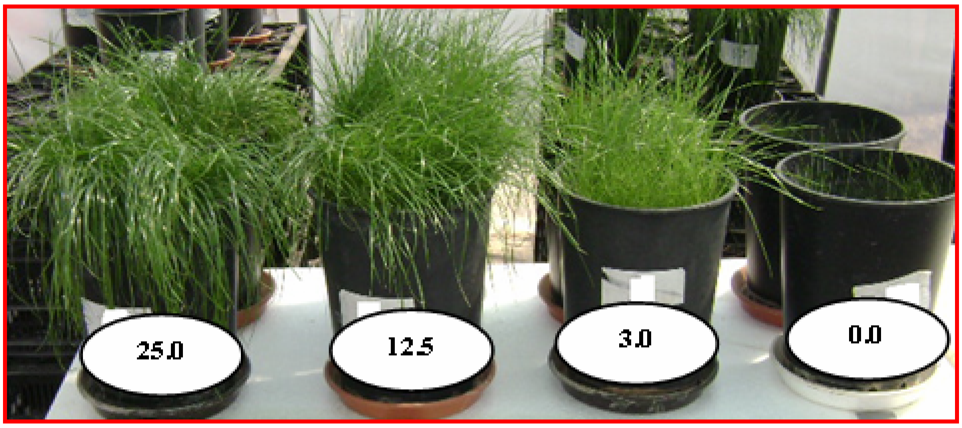


Fig. 4.38: Effect of different application rates [%] of vermicompost on plant vitality and growth

Considered collectively, the results of this study indicate that incorporation of *QR* wood vermicompost into a traditional coal mine substrata (tertiary sand) enhanced growth of potted RSM grass through, at least in part, improved mineral nutrition. In this context, vermicompost proved to be a superior soil amendment to coal mine waste. Finally, the data clearly indicates that wood vermicompost may be an efficient plant growth media for sustainable plant production in coal mine substrata. Present results extend and confirm the hypothesis that the application of vermicompost in tertiary sand substrata increases the budget of essential soil micronutrients and promotes microbial population, which ultimately promotes the plant growth and production at sustainable basis. The land production could be sustained via successive application of organic fertilizers. Moreover, vermicompost not only restores the soil physio-chemical structure, which has been destroyed during digging practices for collecting the coal, but at the same time also enhances the biological nutrient transformation in soils for sustainable land productivity (MENGEL & KIRKBY, 1987; RENATO et al., 2003; IM-ERB et al., 2004; CHAMANI et al., 2008; SUTHAR, 2009).

4.2.2. Field plant experiments

4.2.2.1. Effect of compost and ARK component on soil physicochemical properties

Tertiary sand

The results of the physicochemical characterization of tertiary substrate as affected by wood compost and ARK component are presented in Tables (4.21, 22). Data in Table 4.21 showed the high significant differences between different studied treatments on soil physicochemical properties. In most examined properties, there is no differ significant between the treatments treated only with compost (T2, T3) and the other treated with both compost and ARK component (T5, T6). There are no significant differences between T1, T2 and T5 in the value of dry bulk density (BD), while the highest significant effect was recorded to T4 treatment. The control treatment (T1) showed the highest value (1.33 g cm^{-3}) of BD followed by T2 and /or T5 (1.32 g cm^{-3}), T3 and/or T6 (1.25 g cm^{-3}), T7 (1.23 g cm^{-3}), and finally T4 (1.19 g cm^{-3}). This trend indicated that as rate of applied compost increase the BD was decreased. This could be explained by the composted organic matter improves soil aggregation and structure by reducing the potential for soil compaction (AGGELIDES & LONDRA, 2000; WANAS & OMRAN, 2006). Also, this may be due to the addition of compost caused more porosity added to the soil (RASOOL et al., 2008). The soil water holding capacity (WHC) was improved by the use of *QR* wood compost. Data in Table 4.21 showed the high significant effect of the applied compost on soil water holding capacity (WHC). The high value (47.92 %) of WHC was observed to the treatment T4, while the lowest value was recorded to the control treatment (30.85 %). No significant differences in WHC values between the treatments treated by equal proportions of compost and ARK component (T5, T6) and that treated with the same amount of compost only (T2, T3). However, the treatments T5 and T6 seem to be slightly higher than T2 and T3 treatments in the value of WHC. This may be due to the high WHC of wood compost which resulted from his high content of organic carbon. Also, the obtained results reflect the high ability of ARK to storage water. It can suggest that the addition of compost in sandy soils can facilitate moisture dispersion by allowing water to more readily move laterally from its point of application (PANDEY & SHUKLA, 2006).

The soil EC increased with increasing an application rate of wood compost in soil as reported by ATIYEH et al. (2001) and EGHBALL (2002). The high value of EC observed in treatment T4 followed by T7, T6, T3, T5, T2 and finally T1. High significant effect was recorded to T4, T7, T6 and T3 when compared with T2, T5 and control treatment. It means ARK component did not have any significant impact on soil EC value. In contrary, the high impact of the applied compost may be due to its high content of nutrients and ion concentration (ATIYEH et al., 2002). Wood compost, in association or not with ARK component, provided increases in soil pH, with the highest (5.30) and lowest (3.62) pH values observed at the rate of 10.0 and 0.0 [%] compost, respectively (Table 4.21). Unlike the applied compost, no significant differ in pH value caused by using ARK component. This trend may be the result of the high base content in *QR* wood compost and its large capacity to absorb free protons (H^+) in the soils, this result is similar to that reported by COX et al. (2001). Moreover, Organic fertilization increases soil pH supplying bases, forming alkaline humates during the process of decomposition and synthesis of these residues, and by Al complexing through organic molecules, such as FA and other low molecular weight acids (RENATO et al., 2003; ARANCON et al., 2007). Thus, increasing pH is clearly valuable in these soils in terms of improving microelement availability and reducing the solubility of some toxic elements. Regarding to the effect of the utilized amendments on OM content in tertiary substrate, the OM contents were only affected by the application of wood compost. The high positive impact of the used compost could be explained by its high OM content. It is expected that the compost will incorporate more OM to the soil, because of the greater OM stability in the wood compost (RENATO et al., 2003).

Table 4.21: Soil physical and chemical properties of tertiary substrate as affected by wood compost and ARK component (data represent averages of triplicates)

Properties / Treatments	BD [g cm^{-3}]	WHC [%]	EC [dS m^{-1}]	pH [-]	OM [%]	CEC [cmol kg^{-1}]	TC [%]	TN [%]
T1 (100-0-0)	1.33 a	30.85 d	0.23 d	3.62 e	2.48 d	3.46 d	1.20 d	0.03 b
T2 (97-0-3)	1.32 a	32.43 d	0.24 d	3.86 d	2.81 d	4.17 c	1.25 d	0.04 b
T3 (95-0-5)	1.25 b	35.87 c	0.27 c	3.95 c	3.28 c	4.35 c	1.37 c	0.04 b
T4 (90-0-10)	1.19 c	47.92 a	0.36 a	5.30 a	4.34 a	7.97 a	1.68 a	0.07 a
T5 (94-3-3)	1.32 a	34.98 d	0.25 d	3.87 d	2.82 d	4.18 c	1.24 d	0.04 b
T6 (90-5-5)	1.25 b	37.56 c	0.28 c	3.97 c	3.31 c	4.37 c	1.36 c	0.04 b
T7 (85-7.5-7.5)	1.23 b	44.85 b	0.31 b	4.66 b	3.94 b	6.49 b	1.58 b	0.07 a
LSD $_{0.05}$	0.03	2.90	0.02	0.20	0.44	0.31	0.07	0.02

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3)

The data presented in Table 4.21 showed the high clear effect of wood compost on soil cation exchange capacity (CEC), while no significant effect related to addition of ARK component. The data indicate that, as wood compost increase the CEC increased. The high value of CEC was associated with T4 (7.97 cmol kg^{-1}) treatment followed by T7 (6.49 cmol kg^{-1}), T6 (4.37 cmol kg^{-1}), T3 (4.35 cmol kg^{-1}), T5 (4.18 cmol kg^{-1}), T2 (4.17 cmol kg^{-1}), and T1 (3.46 cmol kg^{-1}). This trend could be explained by wood compost characterized by the greater production of functional groups, which are responsible of surface charges (RENATO et al., 2003). The other reason may be the high proportion of fine particle and OM in compost, thereby increasing the number of exchange sites for mineral nutrients (McCONNELL et al., 1994; PANDEY & SHUKLA, 2006).

The results showed that the total C concentration in tertiary soil was significantly affected by wood compost treatments, especially for treatments T3, T4, T6, and T7. No significant effect observed between treatments T1, T2, and T5 in TC values. The increases of this parameter may be due to their high proportion in compost compared to soil. The soils treated with *QR* wood compost at the rate of 10.0 % and 7.5 %(T4 and T7 respectively) had slightly higher amount of total N (0.07 %) compared to T2, T3, T5 and T6 which gave the same amount of TN (0.04 %), while the soils without compost application (T1) occurred with the lowest value (0.03%). Compost might have produced more residual N in soil than those in control plots. The marked decrease in total N in soils without compost application in comparison with compost treated soils may have been due to larger amounts of total C and N in wood compost that could have provided a larger source of N for mineralization (ARANCON et al., 2007; RASOOL et al., 2008).

There are no significant difference in soil physicochemical properties between the soil sown with RSM and the other cultivated by Autoch grass (Table 4.22). Of course, this trend is due to using the same treatments with each grass. The short time of experiment (6 month) may be insufficient to the emergence of grass effect on soil characteristics. Possibly, leaves falling from grass and also died grass will affect of soil OC, mineralization of N and consequently soil microbial activity. In addition, the expected hormone and enzymes released from grass root may be in long term affected the soil aggregates, structure, and the availability of nutrients from case to another.

Table 4.22: Soil physical and chemical properties of tertiary substrate as affected by different types of grass (data represent averages of triplicates)

Properties / Grass type	BD [g cm^{-3}]	WHC [%]	EC [dS m^{-1}]	pH [-]	OM [%]	CEC [cmol kg^{-1}]	TC [%]	TN [%]
RSM	1.26 a	37.79 a	0.28 a	4.16 a	3.30 a	4.97 a	1.34 a	0.04 a
Autoch	1.27 a	37.48 a	0.27 a	4.18 a	3.28 a	4.96 a	1.36 a	0.04 a
LSD $_{0.05}$	0.02	0.35	0.02	0.03	0.03	0.04	0.03	0.01

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3)

Quaternary sand

The quaternary substrate was very boor in physical properties, it was sandy texture and the proportion of clay and silt were 0.20 and 1.20 % respectively. Thus, a greater quantity of organic material could be added to improve soil structural properties than is necessary to supply the nutrient requirements of a growing crop. It has also been suggested that, this process needs a long time for the emergence of their effect on soil. Table 4.23 and 4.24 summarizes the results of soil physicochemical properties as affected by the applied soil amendments and the sown grasses respectively. Generally, No significant differ in the values of the examined properties among the treatments treated with both wood compost and ARK (Q3) and the other treated only by wood compost (Q5). It means ARK component did not give any positive impact on the studied properties. This may be due to the high quality of wood compost. The data indicated the increase of compost application rate significantly reduced soil BD. The highest value (1.57 g cm^{-3}) of BD occurred in Q1 treatment while the lowest value (1.45 g cm^{-3}) observed in Q2 treatment. There are no significant differences among Q2, Q3, and Q4 treatments in BD values. It can suggest that addition of compost led to increase soil total porosity which in consequently decreased soil BD (AGGELIDES & LONDRA, 2000). The effect of the applied amendments on soil WHC take the same direction of soil BD. The highest (36.37 %) and lowest (29.67 %) values of WHC were appeared in Q2 and Q1 treatments respectively. This could be explained by in a non-aggregated soil any effects on water retention are likely to be due to the properties of the compost material itself. However in a more structured soil changes in both aggregation and pore size and continuity may affect the water holding capacity (MASCIANDARO et al., 2000; BULLUCK et al., 2002; WANAS & OMRAN, 2006; RASOOL et al., 2008).

Electrical conductivity (EC) has been shown to increase with increased compost application rates with the highest concentration (0.17 dS m^{-1}) recorded to Q2 treatment (EGHBALL, 2002; TEJADA et al. 2006). The effect of compost on soil pH is likely to depend both on the initial pH of the compost and the soil pH. Wood compost, in association or not with ARK component, provided increases in soil pH. The highest value (5.75) of soil pH was associated with the high application rate of both wood compost and ARK component (Q2). These trends may be related to the EC and pH values of the applied compost. Depending on the pH of the compost and of the native soil, compost addition may raise or lower the soil/compost blend's pH ((ALEXANDER, 2001)). Also, increase EC with increasing addition rate of compost could be related to high soluble salt in compost than amended soil (MASCIANDARO et al., 2000).

The obtained data in Table 4.23 showed the high clear effect of wood compost on soil OM and CEC values. The highest values (1.54 %, 4.13 cmol kg^{-1}) of OM and CEC respectively were noticed in T2 treatments, while the lowest values were recorded to the unamended soil (Q1). Soil organic matter and clay minerals are the two most important constituents that influence soil CEC. Thus increasing soil organic matter through compost addition is likely to increase CEC. The increase in compost application rate also significantly increased soil TC and TN contents. This also might be due to the high amount of TC and TN in the applied compost. Compost and ARK application at the rate of 5.00 % (Q2) resulted in the highest significant values (0.75 %, 0.03 %) of TC and TN respectively. As well as the lowest values of either TC or TN was founded in control treatments. Usually, the ARK component did not give any remarkable trend of the studied attributes.

Table 4.23: Soil physical and chemical properties of quaternary substrate as affected by wood compost and ARK component (data represent averages of triplicates)

Properties / Treatments	BD [g cm^{-3}]	WHC [%]	EC [dS m^{-1}]	pH [-]	OM [%]	CEC [cmol kg^{-1}]	TC [%]	TN [%]
Q1 (100-0-0)	1.57 a	29.67 c	0.06 c	3.96 c	0.80 c	3.12 c	0.41 c	0.01 c
Q2 (90-5-5)	1.45 c	36.37 a	0.17 a	5.75 a	1.54 a	4.13 a	0.75 a	0.03 a
Q3 (94-3-3)	1.52 b	32.69 b	0.13 b	5.28 b	1.24 b	3.96 b	0.51 b	0.02 b
Q4 (97-1.5-1.5)	1.54 b	32.40 b	0.08 c	4.25 c	0.90 c	3.18 c	0.44 c	0.02 b
Q5 (97-0-3)	1.53 b	32.28 b	0.12 b	5.17 b	1.24 b	3.95 b	0.49 b	0.02 b
Q6 (98.75-0-1.25)	1.57 a	29.78 c	0.06 c	4.09 c	0.83 c	3.15 c	0.42 c	0.01 c
LSD $_{0.05}$	0.03	0.53	0.03	0.32	0.12	0.15	0.04	0.01

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3)

Regarding to the effect of the sown grass (*RSM* and Autoch) on soil physicochemical properties, in due to each grass was cultivated in similar treatments, no significant differences in all studied soil properties observed between the two types of grass (Table 4.24). As described above in tertiary sand experiment, this might be related to the short time of trial and may be in the long run some differences will appear.

Table 4.24: Soil physical and chemical properties of quaternary substrate as affected by different types of grass (Data represent averages of triplicates)

Properties / Grass type	BD [g cm^{-3}]	WHC [%]	EC [dS m^{-1}]	pH [-]	OM [%]	CEC [cmol kg^{-1}]	TC [%]	TN [%]
RSM	1.54 a	32.25 a	0.11 a	4.72 a	1.09 a	3.58 a	0.51 a	0.02 a
Autoch	1.53 a	32.21 a	0.11 a	4.70 a	1.09 a	3.60 a	0.49 a	0.02 a
LSD $_{0.05}$	0.02	0.15	0.01	0.04	0.02	0.03	0.04	0.01

Mean of the same category followed by different letters are significantly different at 0.05 level of probability (see paragraph 3.3)

From the previous discussion it can noticed that, there are a high variations between tertiary and quaternary sediments in soil physicochemical properties and as affected by the applied amendments. Mostly, the values of the examined parameters in tertiary sand were higher than that in quaternary sand, with the exception of pH and BD. This trend might be due to the nature of the configuration of each soil as well as the chemical and physical composition (see Table 3.6). For example, one of the most obvious differences is soil CEC which it was the higher in tertiary sand than quaternary sand. This could be related to high proportion of fine particles (clay and silt) and OM content in tertiary than quaternary substrates (see Table 3.6). The other reason of these variations may be attributed to the tertiary soil contain high amount of lignite (brown coal) while the quaternary sediments is free from it (KOHFAHL, 2004). All of this led to tertiary sand was more responsive to the applied conditioners than quaternary sand.

4.2.2.2. Effect of wood compost and ARK component on planting properties

Fresh and dry matter yield

The effects of wood compost and ARK component on straw (aerial part) fresh matter yield (FMY) for both sown grasses and in different studied soils are presented in Figures (4.39, 40) and summarized in Tables (A36, A37). The data indicate that, both grasses seem to respond positively to the application of wood compost. Generally, the straw FMY of the two types of grasses in tertiary soil was higher than quaternary soils. Regardless of different application rates of the applied amendments in both soils, this could be explained by physical and chemical properties of tertiary sediments were better than that in quaternary sediments (HUETTL & WEBER**,** 2001). High amount of OM, CEC, WHC and proportion of fine particles in tertiary soil may the reason why the cultivated plants in it were more responsive.

In tertiary sand, there was statistically significant difference among treatments for straw FMY in *RSM* and Autoch grasses. Under different application rates of wood compost, the straw FMY for both Autoch and *RSM* grass were increased significantly compared to the control (RASOOL et al., 2008). The straw FMY of Autoch was higher than *RSM* in treatments T1, T2, T5, T6, and T7 while it was lower than *RSM* in treatments T3 and T4. The highest amount (1140.6 and 1165.4 g m^{-2}) of straw FMY for both Autoch and *RSM* grass respectively was observed in treatment T4, while the lowest ones (6.4 and 0.4 g m^{-2}, respectively) was attained by unamended soil (T1). The significant effects of the examined treatments are similar in both studied grasses. There are no significant differences in straw FMY in both grasses among treatments (T2, T5) and between (T6, T7), but treatments T7 and T5 is higher than T2 and T6 respectively (Table A.36). It means the treatments amended with both wood compost and ARK component did not significantly increase FMY when compared with the other treated with wood compost only. This trend could be explained by the plant requirements in quality and quantities are more available in compost than ARK component (MARIA, 2008). The Predominant raising of straw FMY in Autoch than *RSM* grass may be due to Autoch is the Indigenous grass where it can adapt to the surrounding circumstances either in soil or in the air. And because the soil conditions are similar, therefore the variation between the two grasses may be return to the ability of each to deal with climate.

In quaternary sand, also as application rate of wood compost increase the straw FMY of both grasses increased (Figure, 4.39, 40 and Table A.37). In all studied treatments the Autoch grass recorded the higher values of straw FMY than those observed in *RSM* grass. Also, this might be related to Autoch is the native plant. The highest amounts (656.4 and 366.8 g m^{-2}) of straw FMY in Autoch and RSM grass respectively were recorded to Q2 treatment. Unlike to the impact of ARK component on the plants grown in tertiary sand, it had a high effect on that grown in quaternary sand. The amount of straw FMY in both Autoch and *RSM* grass was increased significantly in the treatment Q3 when compared with Q5 treatment. This trend may be attributed to the high ability of ARK component to absorb atmospheric water vapor and storage rain water, especially the quaternary soil is poor in fine particles and OM content (HANGEN & GERKE, 2005). Moreover ARK component is rich in its content of available P and N (data not found). These impacts of ARK component observed in quaternary and unobserved in tertiary soils (among T2 and T5), because tertiary soil was relatively richer in its content of growth components than quaternary soil. The other reason may be different addition rates of the applied amendments in the studied soils, which it was higher in tertiary than quaternary soil.

Finally in both studied soils the positive impact of the applied compost on the examined grasses could be explained by wood compost is rich in all necessary nutrients for plant growth. These increases in straw FMY as results of different application rates of wood compost may be attributed to their content of macro-micronutrients which might enhance the activity of photosynthesis and protein synthesis in the leaves, which in turn encourage photosynthetic process apparatus. In addition the increase in growth characters yield and its attributes by compost may be due to the compost nutrients is readily absorbed by roots (CHAMANI et al., 2008; MARIA, 2008; SUTHAR, 2009).

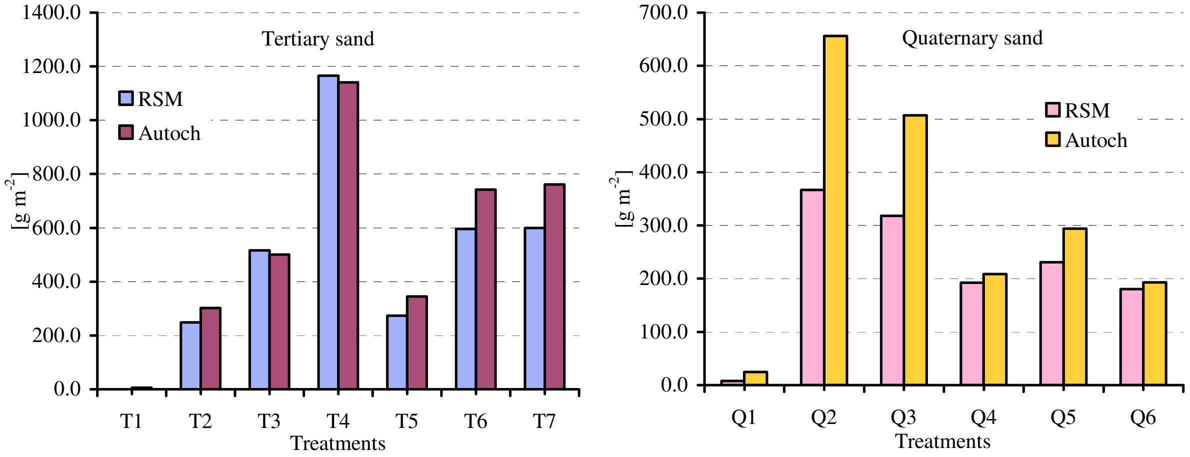


Fig. 4.39: Fresh matter yield of straw in both studied soils as affected by wood compost and ARK component

T1 = 100-0-0, T2 = 97-0-3, T3 = 95-0-5, T4 = 90-0-10, T5 = 94-3-3, T6 = 90-5-5, T7 = 85-7.5-7.5, Q1 = 100-0-0, Q2 = 90-5-5, Q3 = 94-3-3, Q4 = 97-1.5-1.5, Q5 = 97-0-3, Q6 = 98.75-0-1.25 (The numbers is the mass of raw materials [%] , which arranged as: Soil - ARK component – Wood compost)

Data in Figure 4.40 showed the relationships between compost application rates and straw FMY in both selected soils. Through regression analysis, a significant and positive correlation between the straw FMY and the compost application rate was observed, and the best fit was obtained with the linear regression model. Clearly, as wood compost increase the straw FMY was increased in both selected grasses and in each studied soil. Also, data in Figure 4.40 showed the Autoch grass curves in the two soils were in above of the RSM curves. This position reflects that, the amount of straw FMY in Autoch was higher than *RSM* grass. This trend could be related to the Autoch is the native plant. The correlation coefficient in tertiary soil (Autoch-R^2 = 0.99, RSM-R^2 = 0.94) was slightly higher than this in quaternary soil (Autoch-R^2 = 0.97, RSM-R^2 = 0.89). The increase in straw FMY was symmetrically and strongly correlated with the increase in the application rates of wood compost. These trends could be explained by wood compost is rich in all necessary nutrients for plant growth. Compost enhanced soil physiochemical and microbiological properties and correspondingly plant growth parameters (CHAMANI et al., 2008; SUTHAR, 2009).

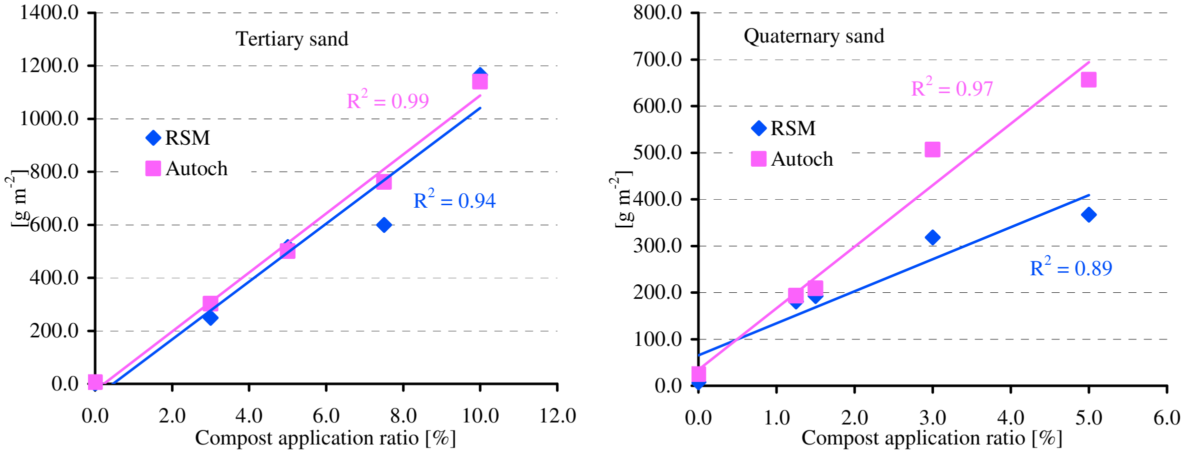


Fig. 4.40: Straw fresh matter yield for the sowed grasses in both studied soils as a function of compost application rates

Finally it is supposed that, the degree of correlation in quaternary soils should be higher than tertiary soil, in due to low amount of OM and TN in quaternary soil. But the opposite was happened, the correlation was similar and slightly higher in tertiary soils. It could be due to the tertiary soil OM is geogenic and more stable, add to this low pH. Therefore, the plants resort to get their requirements from an easier way. In addition, there are another factors in quaternary soil may be preventing the plants from the optimal using of the added compost, like low soil WHC.

Figure 4.41 showed the straw dry matter yield (DMY) of both types of grass in the studied soils. Similarly to straw FMY, the straw DMY of grass was increased significantly as the application rate of wood compost increase (Table A.36, A.37). In tertiary sediments the highest values of straw DMY was recorded to *RSM* grass, while the opposite was happened in quaternary soil. The trends of straw DMY in quaternary soils was in corresponding with the straw FMY. In tertiary sand, in contrary to the trend for straw FMY in treatments T2, T5, T6, and T7 (Autoch > *RSM*) the straw DMY of *RSM* grass in these treatments was higher than that in Autoch grass. This trend may be reflects the nature of plant growth and his content of water. Probably, this also was related to differences proportion of water to dry matter from plant to the other.

In tertiary soil, the highest amount (412.8 and 282.4 g m^{-2}) of straw DMY for *RSM* and Autoch grass respectively was observed in T4 treatments, while the lowest values was recorded to the control. Significantly no differences founded between T2 and T5 treatments in straw DMY, while high significant observed among T3 and T6 treatments. This means addition of 3.0 % ARK component not enough to induce significant changes in dray weight, unlike when adding 5.0 % (Table A.36).

In quaternary soil and as showed in straw FMY, wood compost in association or not with ARK component provided increases in straw DMY for both the two grass (Figure 4.41 and Table A.37). The high significant effect of applied amendments on straw DMY was appeared in Q2 treatments (203.2 and 86.6 g m^{-2}), while the low effect (4.4 and 1.0 g m^{-2}) accompanied with untreated soil for Autoch and RSM grass respectively. Probably, this trend reflects the high poverty of soil which responds to any additions of applied amendments. Also, reflects the high compost content of the necessary requirements for plant growth (CHABBI & RUMPEL, 2004).

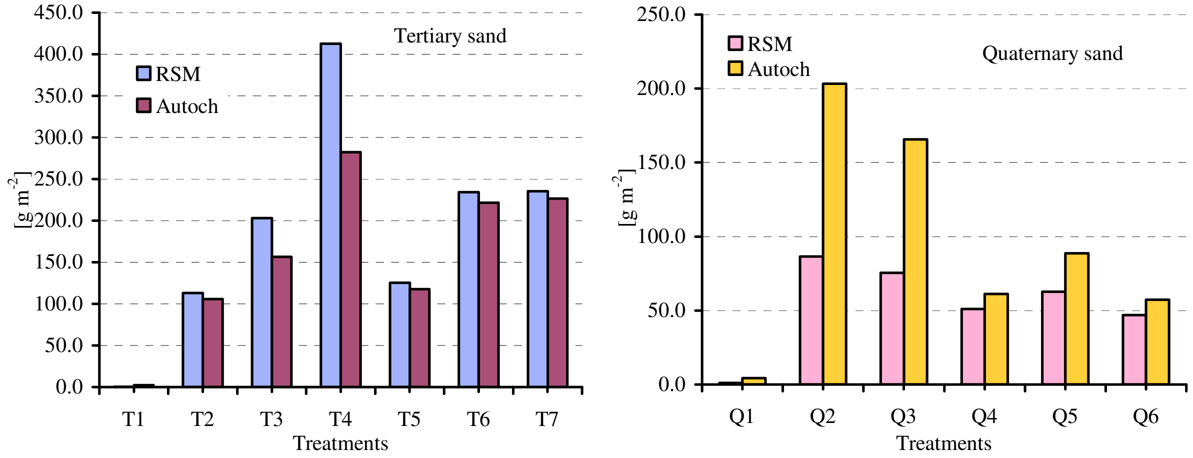


Fig. 4.41: Dry matter yield of straw in both studied soils as affected by wood compost and ARK component

T1 = 100-0-0, T2 = 97-0-3, T3 = 95-0-5, T4 = 90-0-10, T5 = 94-3-3, T6 = 90-5-5, T7 = 85-7.5-7.5, Q1 = 100-0-0, Q2 = 90-5-5, Q3 = 94-3-3, Q4 = 97-1.5-1.5, Q5 = 97-0-3, Q6 = 98.75-0-1.25 (The numbers is the mass of raw materials [%] , which arranged as: Soil - ARK component – Wood compost)

Data presented in Figure 4.42 supported the previous results of straw DMY. The increase in straw DMY was symmetrically and strongly correlated with the increase in the application rates of wood compost. *RSM* grass curve found to be in above position from Autoch grass curve in tertiary sand, while the opposite was happened in quaternary soil. In tertiary sand 99 % of the variance in Autoch straw DMY (R^2 = 0.99) can be explained by variation in the rates of applied compost. Likewise, 95 % of the variance in RSM straw DMY (R^2 = 0.95) can be explained by variation in the rates of applied compost (Figure 4.39). In quaternary sand, also there are a high correlation coefficient between straw DMY (R^2 = 0.95 and R^2 = 0.83, for Autoch and *RSM* grass respectively) and application rates of wood compost. These trends means strongly responsive of the sowed grass for any addition rates of wood compost, especially the soil was very poor in the plant growth requirements (CHABBI & RUMPEL, 2004; NATHAN, 2004; CHAMANI et al., 2008; MARIA, 2008; SUTHAR, 2009).

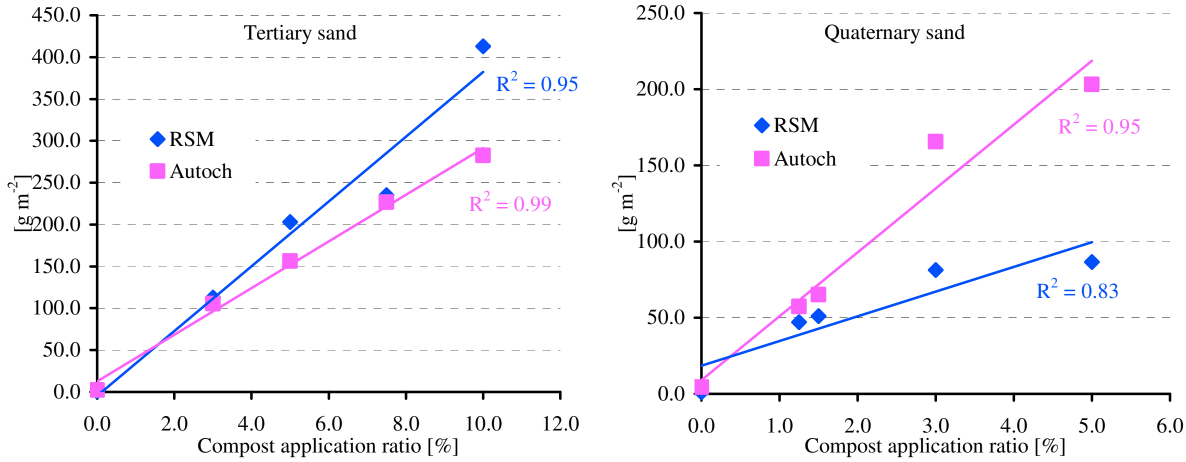


Fig. 4.42: Straw dry matter yield for the sowed grasses in both studied soils as a function of compost application rates

Data of root dry matter yield in both amended soils and as affected by compost and ARK component are presented in Figures (4.43 and 4.44) and summarized in Tables (A.36 and A.37). Application of wood compost significantly increased not only the straw matter yield but also balanced this increases with larger root size (WEBER et al., 2007). The data show that, *RSM* grass attained the highest values of root dry matter yield (DMY) in both studied soils when compared with Autoch grass. This trend may be attributed to the difference of root nature growth from plant to other. Whereas the radical root of *RSM* grass was thicker, have many lateral branches and adventitious root than those of Autoch grass root. Compost improves soil's water retention and other physical properties, enhancing root proliferation and development. Moreover, the root DMY of both types of grass were in tertiary sediments higher than that in quaternary soil. This could be attributed to the soil physical and chemical properties of tertiary substrate were better than that in quaternary sand, particularly tertiary sand contain higher amount of fine particle and OM which enhance storage water and nutrients that in turn necessary for root growth (MASCIANDARO et al., 2000; CHABBI & RUMPEL, 2004; JOHNSON et al., 2006) . Such favorable effects of tertiary soil on grass yield could be attributed to the high stimulation effect of compost NPK on number and weight of grass and nitrogen activity which in turn reflected positively on grass yield attributes. This stimulation effect of compost may be less in quaternary soil.

In tertiary soil, the highest values (497.0 and 234.6 g m^{-2}) of root DMY for *RSM* and Autoch grass respectively were noted in T4 treatment while the lowest ones (3.8 and 6.0 g m^{-2} for *RSM* and Autoch grass respectively) obtained from control treatment. Significantly no differences appeared between the treatments treated by compost only (T2 and T3) and the other mixed with both compost and ARK component (T5 and T6) respectively. The plant roots may be preferred to absorb water and nutrients from the easily media (compost), as suggested by PANDEY and SHUKLA (2006). Compost improves soil quality and protects water quality (JOHNSON et al., 2006). Likewise, the highest amounts (215.4 and 88.0 g m^{-2}) of root DMY in quaternary soil for *RSM* and Autoch respectively were recorded to Q2 treatments. Unlike the tertiary soil addition of wood compost and ARK component together increased significantly the root DMY when compared with the treatments treated by compost only. As suggested above this may be due to quaternary sand was poor in fine particles and OM contents which is offset by the presence of ARK component.

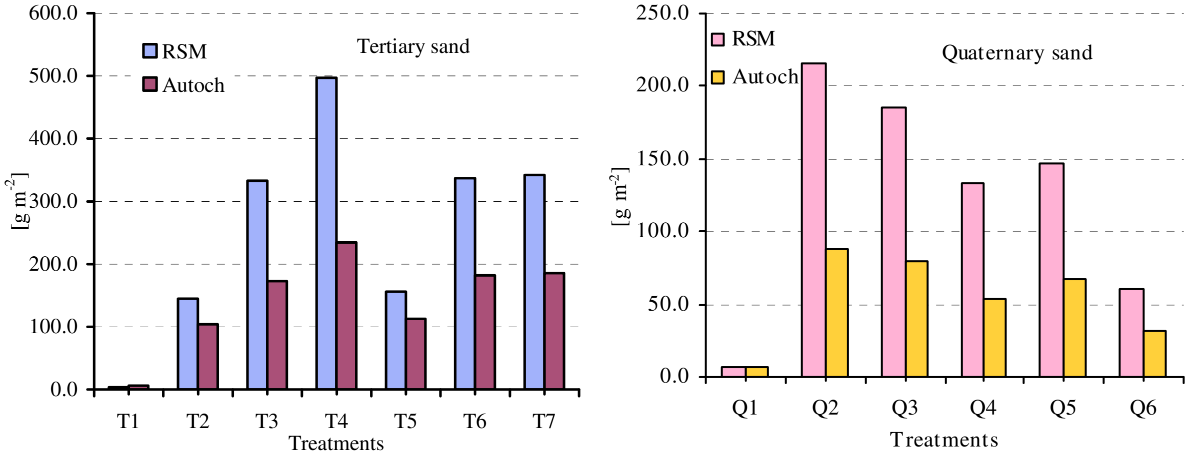


Fig. 4.43: Dry matter yield of root in both studied soils as affected by wood compost and ARK component

T1 = 100-0-0, T2 = 97-0-3, T3 = 95-0-5, T4 = 90-0-10, T5 = 94-3-3, T6 = 90-5-5, T7 = 85-7.5-7.5, Q1 = 100-0-0, Q2 = 90-5-5, Q3 = 94-3-3, Q4 = 97-1.5-1.5, Q5 = 97-0-3, Q6 = 98.75-0-1.25 (The numbers is the mass of raw materials [%] , which arranged as: Soil - ARK component – Wood compost)

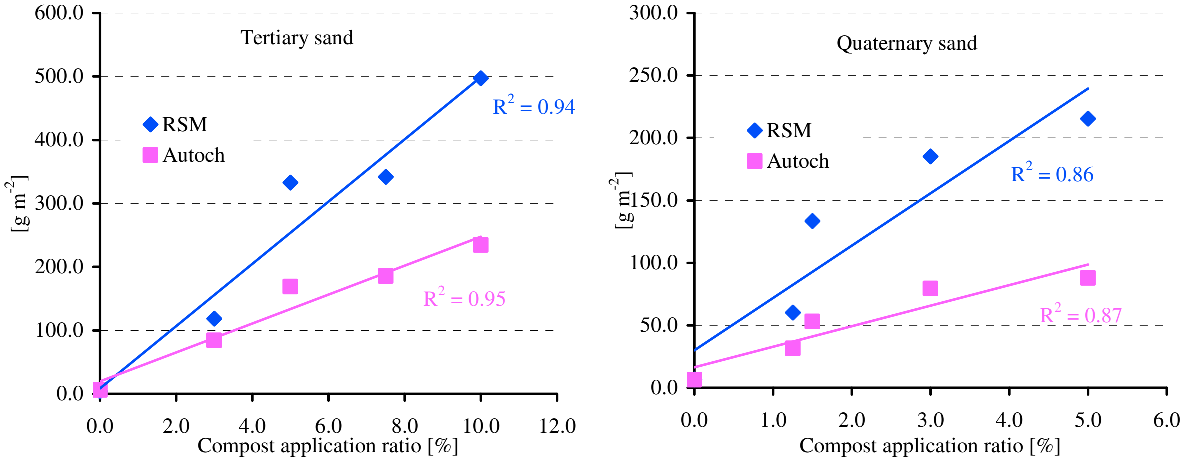


Fig. 4.44: Relationships between the rate of applied compost and dry matter yield of root for the grown grass in both studied soils

Results in Figure (4.44) showed the root DMY as a function of compost application rates which confirmed the previous results of Figure (4.43). The data shows the RSM grass in both studied sites was in above position from Autoch grass. This reflects the higher root DMY of *RSM* grass than Autoch grass (CHABBI & RUMPEL, 2004). The correlation coefficient between root DMY and different rates of applied compost was higher in tertiary than that in quaternary soil. The values of R^2 were 0.94 and 0.95 (tertiary soil) and achieved 0.86 and 0.87 (quaternary soil) for *RSM* and Autoch grass respectively. These mean that, the grass grown in tertiary sediments were more responsive to the application rates of wood compost than that sowed in quaternary soil. Preference for tertiary soil could be related to their physicochemical properties which may be encourages decomposition of the added compost and provides and maintain his nutrients in available form to absorb by plant. High filtration rate of quaternary sand may be contributing of leachate the compost nutrients, which prevent the plants to benefit from them for a long time (MASCIANDARO et al., 2000; CHAMANI et al., 2008; MARIA, 2008; SUTHAR, 2009).

Plant height and covering percentage

Seeds contain their own food-store. They will germinate successfully in nutrient-free material, just it need water and suitable conditions. However, their food-store will soon run out. They then need nutrients from the growing medium to promote healthy growth. Results indicate that wood compost increased germination rate which maintain soil moisture content in an optimal level, especially the water holding capacity of the studied soils was very low. Data in Figures (4.45, 4.46) and summarized in Tables (A.36, A.37) showed the effect of wood compost in association or not with ARK component on the height of the grass grown in selected soils. The grass grown in tertiary soil recorded the highest height values, when compared with those in quaternary sand. As suggested above this may be reveals to the differences between both soils in their physicochemical properties and its relation with the applied amendments. A little difference were found between the two sowed grass, which they were similar in treatments T1 (5.0 cm), T4 (20.0 cm), T6 (20.0 cm), and T7 (20.0cm) (tertiary soil) and Q1 (5.0 cm), Q3 (10.0 cm), Q4 (10.0 cm), Q5 (10.0 cm) and Q6 (8.0 cm) (quaternary soil). Simple differences of plant height was in favor for Autoch grass and appeared in treatments T2, T3, and T5 (Tertiary soil), while this trend showed only in treatment Q2 (quaternary soil). Addition of ARK component did not give any mention trend of grass height, with the exception of T6 treatment which it was higher than T3 treatment. Generally, in both sites addition of wood compost increased significantly grass height.

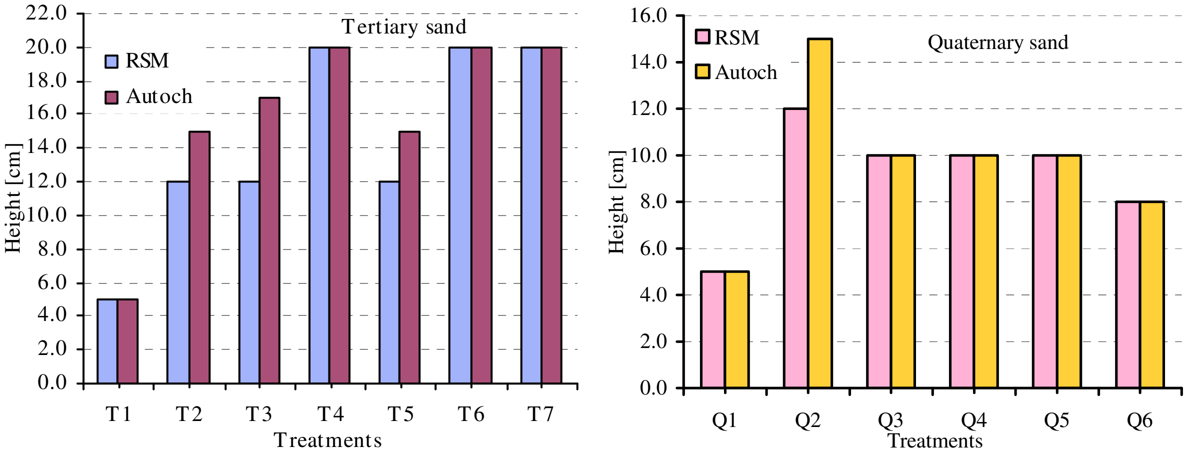


Fig. 4.45: plant height for the grown grass in both studied soils as affected by wood compost and ARK component

T1 = 100-0-0, T2 = 97-0-3, T3 = 95-0-5, T4 = 90-0-10, T5 = 94-3-3, T6 = 90-5-5, T7 = 85-7.5-7.5, Q1 = 100-0-0, Q2 = 90-5-5, Q3 = 94-3-3, Q4 = 97-1.5-1.5, Q5 = 97-0-3, Q6 = 98.75-0-1.25 (The numbers is the mass of raw materials [%] , which arranged as: Soil - ARK component – Wood compost)

Regarding to the effect of wood compost only on grass height, data in Figure (4.46) observed the positive relationships between plant height and application rate of compost, but it was not steady for both grasses. In tertiary soil *RSM* grass recorded the higher value of R^2 (0.91) than Autoch grass (R^2 = 0.83), while the opposite trend was happened in quaternary sand (R^2 = 0.92 and 0.81 for Autoch and RSM grass respectively). This may be due to another factors affected the plant height, like nature of plant growth and physiological process. Also, different height may be due to the effect of plant covering percentage (distance between plants). This might be due to the reason that the greater plant spaces provided more space to plants to receive light resulting in more photosynthesis and thus more growth. Furthermore the plant roots had more chance to spread and take nutrients from greater surface area (CHABBI & RUMPEL, 2004; JAVED et al., 2009).

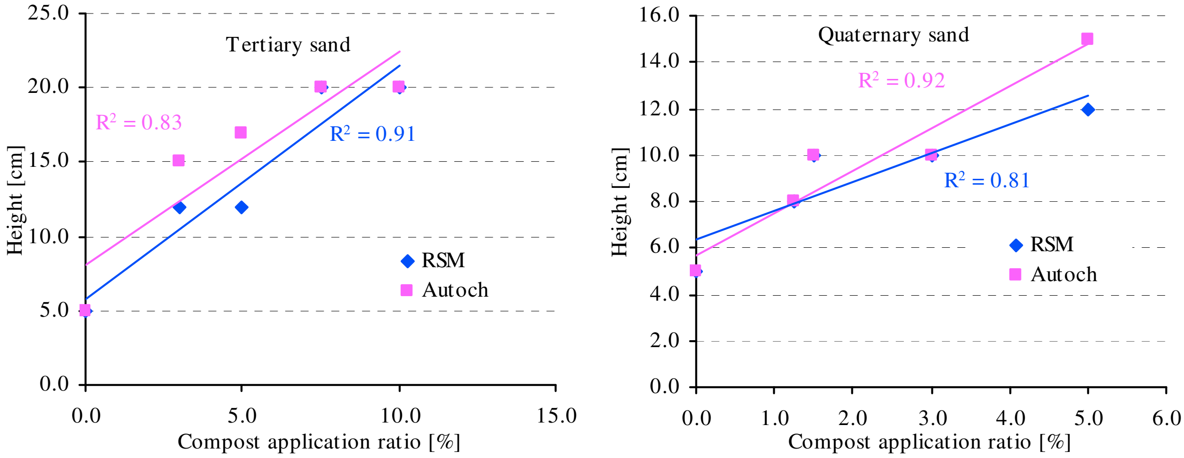


Fig. 4.46: Relationships between the rate of applied compost and plant height for the grown grass in both studied soils

Emergence density and subsequent plant population of the selected grasses was influenced by the used soil amendments at both sites. The great effect of wood compost and ARK component on grass covering percentage was showed in Figures (4.47, 4.48) and recorded in Tables (A.36, A.37). The clear observation was grass covering percentage increased significantly when the rates of applied compost increases. The obtained results demonstrated the covering percentage of both grasses in tertiary soil was higher than those grown in quaternary soil. This reflected germination rate of the sown grasses, which could be affected by soil water retention. Clay and OM contents of the tertiary soil were associated with higher available water-holding capacity (WHC) than in the quaternary soil. Reducing WHC in quaternary soil may be also increasing the potential for seed-rot. The other reason for the discrepancy in the grass covering rate may be the precipitation, which affects of the distribution of seeds. Poor distribution of grasses grown in quaternary soil may be due to death some plants which can not get its requirements from water and nutrients (Figure 4.47, 48). Probably, topographical variation in plots at both sites may have increased variance in density and plant growth measurements (NATHAN, 2004). Different rates of applied amendments in both sites may be affected the grass covering percentage.

Regarding to the differences between both grasses, Autoch grass appeared with the highest covering in both sites. It could be attributed to Autoch is the native plant. The highest values of covering percentage recorded to the treatment treated by the greater amount of wood compost. In tertiary soil, treatments T4, T6, and T7 achieved the same values of plant percentage (90.0 and 95.0 %) for *RSM* and Autoch grass respectively, while the control treatments recorded 1.0 % covering for both grasses. In quaternary soil, the highest values observed in Q2 (80.0 and 75.0 % for Autoch and *RSM* respectively) followed by Q3 (75.0 and 60.0 % for Autoch and RSM respectively), Q5 (60.0 and 55.0 % for Autoch and *RSM* respectively), Q4 (40.0 % for both grasses), Q6 (30.0 % for both grasses), and Q1 (10.0 % for both grasses). This trend reflected the high positive impact of wood compost on grass covering, as evidenced by the poverty of the untreated soil. Addition ARK component and compost together increased significantly plant density in both sites when compared with soil treated only by compost. This could be due to ARK component characterized by high ability to absorb and store water that necessary for seed germination.

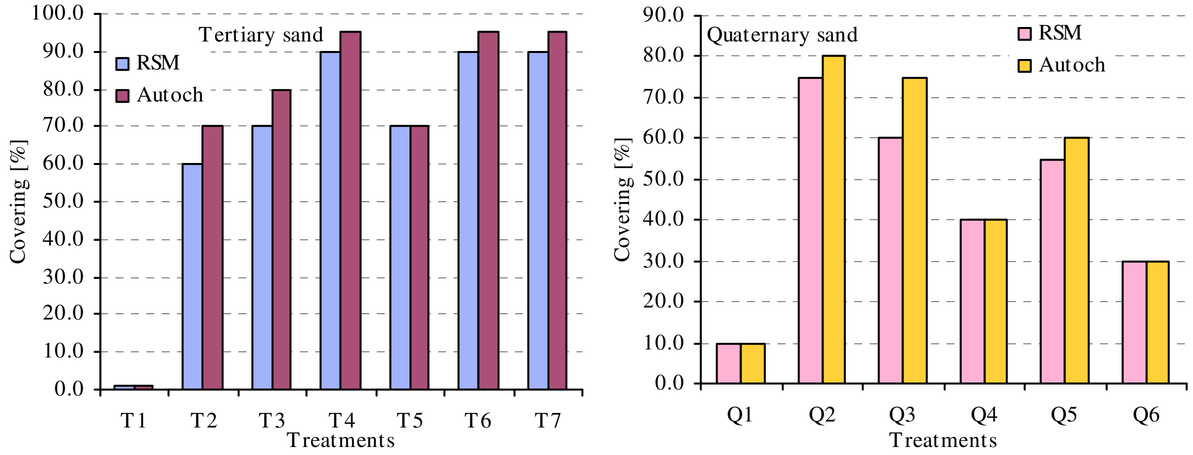


Fig. 4.47: Covering percentage for the grown grass in both studied soils as affected by wood compost and ARK component

T1 = 100-0-0, T2 = 97-0-3, T3 = 95-0-5, T4 = 90-0-10, T5 = 94-3-3, T6 = 90-5-5, T7 = 85-7.5-7.5, Q1 = 100-0-0, Q2 = 90-5-5, Q3 = 94-3-3, Q4 = 97-1.5-1.5, Q5 = 97-0-3, Q6 = 98.75-0-1.25 (The numbers is the mass of raw materials [%] , which arranged as: Soil - ARK component – Wood compost)

Data in Figure (4.48) showed plant covering percentage as a function of applied rates of wood compost, which demonstrated the previous results in Figure (4.47). The Autoch grass appeared with the highest plant density, reflected by the higher position of his curves in both sites. Also, it was clear that, Autoch grass was higher in response to application rate of compost than *RSM* grass. Both grasses appeared with the same correlation (R^2 = 0.88 and 0.84) in the two types of soil for Autoch and RSM grass respectively. This trend could be related to different germination rate in both grasses and ability of germinated plants to uptake their requirements from water and nutrients which in turn affected by compost application rates (NATHAN, 2004; PANDEY & SHUKLA, 2006; MARIA, 2008; JAVED et al., 2009).

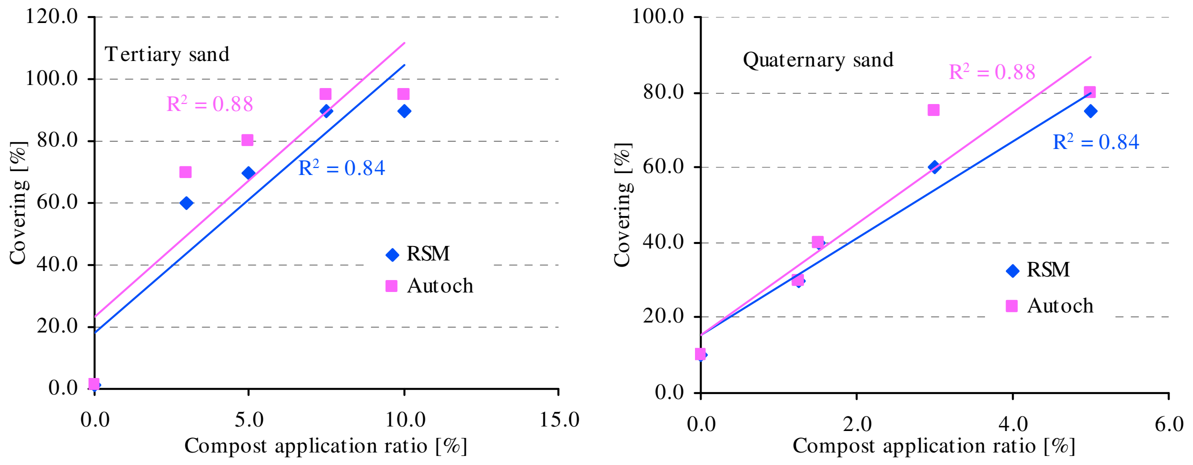


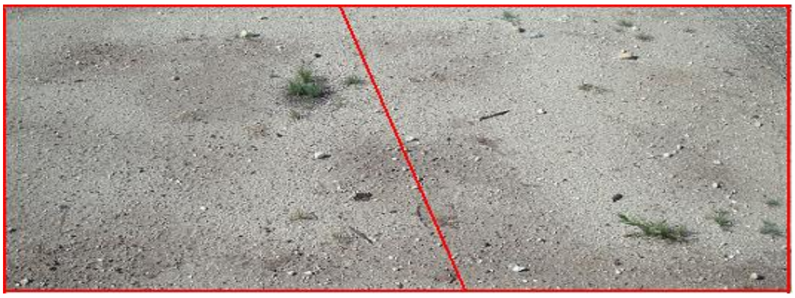
Fig. 4.48: Relationships between the rate of applied compost and covering percentage for the grown grass in both studied soils

Others

Although the digital results are a good indicator for the studied factors, but if it proved by pictured field results could be better. Figures (4.49, 4.50) summarized all the previous plant results as natural field scenes. The photos of final plant growth with various applied amendments indicated that, the addition of wood compost to tertiary and quaternary sediments positively impacted *RSM* and Autoch grasses vitality, healthy and growth. Grass height and quality increased as wood compost percentage increased. The results showed the grass grown in tertiary sand were better in quality, vitality and greener than that grown in quaternary soil. These high variations between the selected soils could be attributed to their physicochemical properties, where it was the best in tertiary than quaternary soil. High contents of OM and fine particles in tertiary substrate are the famous factors which affected soil water retention and consequently plant growth parameters. May be these soil properties encouraged soil microorganisms to decompose the applied compost, which will affects the compost nutrients availability.

Also, the collected photos in each site show that, as compost application rate increased the covering percentage increased. There are a high variations appeared between control and treated treatment. Reflects the studied soils were very poor and the used ameliorations are richer. In tertiary soil, a combination of ARK component and wood compost (T5, T6) led to increase the areas encumbered with grass when compared with grass distribution in the treatment treated with wood compost only (T2, T3). Differences between compost applied treatments may be due to their contents of available N, P and K (MENGEL & KIRKBY, 1987). The plants grown with 10.0 % (T4) wood compost seems to be stronger than the others. In quaternary soil, the best plants growth appeared in Q2 treatment, while the low density and weak plants occurred in untreated soil (Q1). Differences between treatments Q3 and Q5 observed the positive impact of ARC component. Finally, the Autoch grass seems to be more coverage, stronger and greener than *RSM* grass in tertiary sand, while the differences among them were not clear in quaternary soil. This trend reflects the effect of plant growth nature and soil type, also Autoch is the native and indigenous plant (FELINKS et al., 1999a, b).

Considered collectively, the results of this field plant experiments indicate that incorporation of *QR* wood compost and /or ARK component into a traditional coal mine substrates (tertiary and quaternary sand) enhanced growth of *RSM* and Autoch grasses through, at least in part, improved mineral nutrition. The greater impact in both sites was observed to wood compost, while limited beneficial effects recorded to ARK component. In this context, wood compost proved to be a superior soil amendment to coal mine waste. Finally, the data clearly indicates that wood compost may be an efficient plant growth media for sustainable plant production in coal mine substrates. Present results extend and confirm the hypothesis that the application of wood compost in tertiary and quaternary sediments increases the budget of essential soil micronutrients and promotes microbial population, which ultimately promotes the plant growth and production at sustainable basis. The land production could be sustained via successive application of organic fertilizers. Moreover, wood compost not only restores the soil physio-chemical structure, which has been destroyed during digging practices for collecting the coal, but at the same time also enhances the biological nutrient transformation in soils for sustainable land productivity (MENGEL & KIRKBY, 1987; RENATO et al., 2003; IM-ERB et al., 2004; CHAMANI et al., 2008; SUTHAR, 2009).



RSM T1 (100 – 0 – 0) **Autoch**

Autoch T2 (97 – 0 – 3) ***RSM*** **Autoch** T3 (95 – 0 – 5) ***RSM***

Autoch T4 (90 – 0 – 10) ***RSM*** **Autoch** T5 (94 – 3 – 3) ***RSM***

Autoch T6 (90 – 5 – 5) ***RSM*** ***RSM*** T7 (85 – 7.5 – 7.5) **Autoch**

Fig. 4.49: View of the field trial for both *RSM* and Autoch grasses in tertiary sand at the end of experiment

RSM Q1 (100 – 0 – 0) **Autoch** ***RSM*** Q2 (90 – 5 – 5) **Autoch**

RSM Q3 (94 – 3 – 3) **Autoch** ***RSM*** Q4 (97 – 1.5 – 1.5) **Autoch**

RSM Q5 (97 – 0 – 3) **Autoch** ***RSM*** Q6 (98.75 – 0 – 1.25) **Autoch**

Fig. 4.50: View of the field trial for both *RSM* and Autoch grasses in quaternary sand at the end of experiment

5. CONCLUSIONS

This thesis aimed to contribute towards the identification of a system for managing and composting of wood, in order to reduce the CO_2 produced by burning wood. As well as the utilization of wood compost for sustainable agriculture, with particular regards to reclamation coal mine wastes in two selected sites.

The main experimental research undertaken included composting and vermicomposting of wood under greenhouse controlled conditions, greenhouse plant experiment, field plant experiments. In each experiment there are many laboratory measurements were carried out, in order to understand and interpret the changes that occurred.

Compost experiments focused on evaluation of some factors affected the wood composting like, wood type, wood shape and size, types of nitrogen resources, mixing ratios, water types, and worm types. Also monitored some characteristics changed during composting like, temperature, CO_2, biodegradation degree, OM, TOC, TEC, humification parameters, and maturity parameters. In addition, physicochemical properties and morphological features of wood compost product was evaluated. The most important measurements that have been implemented were the cumulative amount of CO_2 produced during composting and the amount of CO_2 evolved by burning of wood.

Also, some vermicompost samples were selected to study its thermal stability which compared with a soil sample (Niedermoorgleys) by using thermogravimetric analysis technique. Further investigation was achieved to evaluate the effect of charcoal as a source of carbon on vermicompost stability. Moreover some selected vermicompost samples were used to examine its microstructure under scanning electron microscope which compared also with the same soil used in thermal analysis.

Plant experiments were carried out in two scales, the first in greenhouse and relied on evaluate the effect of wood compost produced from the first compost experiment on tertiary soil properties and their grass grown. The second plant experiment was done in field and established to examine the effect of wood compost on soil properties of two selected soils (tertiary and quaternary sand). Also, in both sites there are two types of grasses (*RSM* 7.2.1 and Autoch) were selected to investigate their responds to the applied wood compost. These experiments focused on the correlation of wood compost properties with soil and grass yield parameters, the changes in soil quality and the plants production following the short term compost application to coal mine soils.

The conclusions drawn from the first compost experiment are summarized below:

a) Composting of *QR* and *PS* woods for one month followed by vermicomposting for two months of different studied treatments resulted in the compost reaching stability after 70 days from the beginning of experiment.

b) It was demonstrated that under different studied treatments, temperature was increased up to the day 21 and then it was decreased which it was stabilized in the last four weeks. High temperature values were recorded to *QR* wood treatments, while the low values observed in *PS* wood mixtures. Addition of earthworms (*EF, DV*) did not show any changes of compost temperature curve.

c) The obtained data show that carbon dioxide produced was increased with the increase of decomposition period. This increase was found only at three week where the produced CO_2 was decreased after that up to end of the experiment. The high cumulative amounts of produced CO_2 were found with *QR* wood compost while the low amount was recorded for *PS* wood compost. Cumulative amount of CO_2 produced during composting period was lower than that produced by combustion in both types of wood (*QR and PS*). The results showed composting of wood can reduce the emitted CO_2 up to 50 % when compared with the amount of CO_2 produced from combustion of wood.

d) Degree of biodegradability was increased with the increase of incubation period until the compost reached to the stability phase at 70th day.

e) During the 100 day period, there was a high level of organic matter evolution, indicated by the high changes of organic C, total extractable carbon, as well as of the humification parameters. The decrease of OM, TOC and TEC contents with time, associated with an increase towards constantly high values of DH, HR and decrease the HI value suggests the reaching of an acceptable level of compost maturity. Under different studied parameters, fulvic acid was increased until the 70th day after that it was decreased till the end of composting period. Humic acid was increased up on the first 56 days after that decreased till the 84 day which it was increased till the end of composting period. Finally, under different studied parameters, the rates of change either decrease or increase in *QR* wood treatments was greater than *PS* wood mixtures.

f) Physical and chemical properties of the final products of wood compost and as affected by the studied factors are summarized in the following:

    A. The compost of *QR* have high values of dry bulk density compared with that of *PS* compost, while the values of water holding capacity in *PS* wood compost were higher than those in *QR* wood compost.

    B. Electrical conductivity as an indicator of total soluble salt in *QR* compost was higher than *PS* compost, while the pH values recorded an opposite trend for the studied wood types. The *QR* wood compost contains a low amount of OM, TOC, and TC in comparison with those in *PS* wood compost. Total nitrogen content and cation exchange capacity in *QR* wood compost were higher than *PS* wood compost.

    C. Data showed the values of all examined nutrients (N, P, Ca, Mg, K, Fe, Mn, Zn, and Cu), either in total or available case was in *QR* compost higher than that in *PS* compost.

g) In both types of wood, the treatments irrigated with compost water for one month were better than that moisted with tap water all composting period. Also, the high positive impact of wood composting recorded to the mixtures of 1:3 while 1:1 (wood : LM) came in second order. The high significant influences in the degradation of wood recorded to the treatments infected by *EF* worm followed by *DV* worm and finally uninfected treatments.

The conclusions drawn from the second compost experiment can be summarized as follows:

a) Mixing *QR* wood with different types of nitrogen resources (LM and HM) demonstrated the best ones was HM component. The used mixtures in terms of responsiveness and accelerate the decomposition were arranged as 1WC: 2HM followed by 1WC:1LM:1HM and finally 1WC:2LM.

b) Treatments infected by *EF* worm accelerated mineralization rate of wood. The mixtures irrigated with compost water for one month and after that moisted with tap water and infected by *EF* worm was better than that free from worms and moisted with compost water all composting period.

c) Similarly, as showed in the first compost experiment, temperature and CO_2 were increased up to the day 21 and then it was decreased which it was stabilized in the last four weeks. Throughout composting the highest values of temperature and CO_2 occurred in the mixtures of wood and HM followed by wood and both LM and HM and finally wood mixed with LM. Under different studied mixtures the cumulative amount of CO_2 produced during composting period was lower than that evolved by burning wood. Composting of wood reduced CO_2 emission up to 40 % of the combustion wood CO_2.

d) Biodegradation degree of *QR* wood mixed with HM component achieved the highest degradation rate when compared with the others.

e) The decline rate of OM, TOC and TEC contents of the wood treated with HM was higher than that of wood mixed with LM. The high contents of microorganisms, N, P and other nutrients may be accelerated decomposition and mineralization of wood. Also, during composting the values of HA, FA, DH, HR were the highest in the mixture of wood and HM while the HI values attained the opposite trend.

f) Physical and chemical properties of the final products of *QR* wood compost and as affected by the studied factors are summarized in the following:

    A. Values of all studied properties were significantly increased as HM presence or increase (except pH and C:N ratio).

    B. The compost produced from 1WC:2HM mixture gave the high value of bulk density followed by 1WC:1LM:1HM and finally 1WC:2LM mixture. The values of water holding capacity of compost produced from wood mixed with HM was higher than that of wood mixed with LM.

    C. The high compost contents of EC, OM, TOC, CEC, and TN were recorded to the mixture of 1WC:2HM followed by 1WC:1LM:1HM and finally 1WC:2LM mixture. While the compost values of pH and C:N ratio observed an opposite trends.

    D. The obtained results demonstrated that, the values of (N, P, Mg, K, Zn, and Cu), either in total or available case was in 1WC:2HM compost higher than the other mixtures, while total or available amounts of Ca, Fe, and Mn were the highest in the 1WC:2LM mixture. For all examined nutrients the mixture of 1WC:1LM:1HM occurred with intermediate values between the other two mixtures.

The conclusions drawn from thermal and microstructure analysis are summarized below:

a) The thermal analysis of the selected vermicompost samples show that, the vermicompost produced from the mixture of *QR* wood and HM seems to be more thermostable when compared with the other mixture, but all vermicompost samples were less stable when compared with soil sample. The selected vermicompost samples from both first and second compost experiments showed, up to 200° C temperature the mass loss was due to free water and bound water (It was in vermicompost samples higher than soil sample). Mass loss from 200 to 550° C is due to easily oxidizable organic forms and it was higher in vermicompost than soil. In this stage the soil OM seems to be more stable than vermicompost which can be explained by a more intense bond between the organic and inorganic components. At higher temperatures (T> 550° C) no significant detectable was appeared of soil organic matter. In contrast, the vermicompost treatments showed a high proportion of stable groups, especially the aromatic compounds. These statements seem to be importance particularly for the practical application of the wood compost in terms of their long-term effect in the soil. The application of charcoal, showed no additional stabilizing effect of vermicompost.

b) Regarding to the structure shape, the micrographs observed that the vermicompost produced from the mixtures of wood and LM is sub-angular blocky, while the structure of vermicompost resulted from 1*QR*:2HM+*EF* mixture descried as fibers and sticks. Also, the obtained results indicated the structure of vermicompost was homogenous since it has one form of the structure forms. As well, the particle sizes were more uniform, eliminating large pore spaces. Within vermicompost samples, the highest ratio of surface area : volume was recorded to the mixture of 1*QR*:2HM+*EF*, while there are no differences evident among the vermicompost produced from 1*QR*:2LM+*EF* and 1*QR*:3LM+*EF* treatments. Also, the data show that, vermicompost structure characterized with high homogeneity and ratio of surface area to volume compared to those in soil structure.

The conclusions drawn from greenhouse plant experiment are summarized below:

a) Incorporation of *QR* wood vermicompost produced from first compost experiment into a traditional coal mine substrate (tertiary sand) enhanced soil physical attributes. The WHC and TP increased significantly as the vermicompost rates increased, with the highest values recorded to 25.0 % vermicompost application rate. In contrast, increased rates of vermicompost reduced significantly soil bulk and particle density.

b) Application of different rates of vermicompost had significantly influenced the tertiary soil chemical properties. The soil amended with vermicompost had significantly higher values of EC, pH, OM, TOC, TC, TN, and TS than the untreated soils.

c) The summations of exchangeable bases were increased significantly with the increase of vermicompost application rate, while increasing vermicompost application rate led to decreased total exchangeable acidity. Also, the effective and potential cation exchange capacity (ECEC and PCEC) and in consequence the base saturation percentage (BS) were significantly increased with the increase of vermicompost application rate.

d) The addition of vermicompost increased soil resistance to change in pH, the highest resistance was recorded for the treatments with higher addition rates of vermicompost (12.5 and 25.0 %).

e) Available values of N, P, K, Ca, Mg, Cu, Zn and Mn in the soil treated with vermicompost was higher than their values in untreated soil, while Fe recorded an opposite tend.

f) Diagnosis of the symptoms of nutrient deficiency in *RSM* 7.2.1 grass grown in tertiary soil with application of various doses of wood vermicompost was confirmed by analysis of the complete straw. The data indicate that, the uptake of (N, P, K, Ca, Mg, Zn, and Mn) did not differ significantly at addition rates of 3.0 and 25.0 % vermicompost compared with control and 12.5 % vermicompost respectively. The Fe content of plant tissues decreased significantly with increasing vermicompost in the base media compared to the control. No significant differences in Cu concentration were found between plants grown in different studied treatments.

g) Under different application rates of vermicompost, the fresh and dry matter yield for both straw and roots of *RSM* grass were increased significantly compared to the control. The high relative increase of fresh and dry weight for both straw and roots was recorded in the 25.0 % followed by 12.5 % and finally the 3.0 % vermicompost. Also, the numbers of plants per pot and plant height were increased significantly with increasing the application rate of wood vermicompost.

h) Considered collectively, vermicompost not only restores the soil physio-chemical structure, which has been destroyed during digging practices for collecting the coal, but at the same time also enhances the biological nutrient transformation in soils for sustainable land productivity.

The conclusions drawn from field plant experiments are summarized below:

a) Application of *QR* wood compost produced from the second compost experiment in association or not with ARK component led to improve soil physicochemical properties and plant growth parameters.

b) In tertiary sand, there are no significant influences in the values of most studied properties between the treatments treated only with compost and the other treated with both compost and ARK component, while the opposite was happen in quaternary soil.

c) Mostly, the values of the examined parameters in tertiary sand were higher than that in quaternary sand, with the exception of pH and BD. The tertiary sediments were more responsive to the applied amendments than quaternary soil.

d) Addition of *QR* wood compost and/or ARK component in both studied soils led to decreased soil bulk density and increase soil water retention (WHC). The lowest values of BD and the highest amount of WHC were inherent to the high rate of applied compost.

e) Application of wood compost had significantly influenced the tertiary and quaternary soil chemical properties. The soil amended with wood compost had significantly higher values of EC, pH, OM, CEC, TC, and TN than the untreated soils.

f) In due to Autoch grass is the native and indigenous plant, it was observed the highest positive impact to the applied amendments when compared with *RSM* grass.

g) The straw fresh and dry matter yield, as well as root dry matter yield of the two types of grasses in tertiary soil was higher than those in quaternary soils. In both selected sites increased application rate of wood compost led to increase the production of straw and root for either Autoch or *RSM* grass, with the highest values recorded to the treatments treated by the highest amount of wood compost.

h) Unlike to the impact of ARK component on the plants grown in tertiary sand, it had a high effect on that grown in quaternary sand.

i) The positive relationships between plant height and different application rates of wood compost were observed, but it was not steady for both grasses. Also, Emergence density and subsequent plant population of the selected grasses was influenced by the used soil amendments at both sites.

6. RECOMMENDATIONS

The following aspects are recommended for future investigations and study,

1. Under the implemented experiments conditions, the *QR* wood is better than for composting than *PS* wood. In large scale it can suggested that, *QR* wood should mixed with HM component, irrigated for one month with compost water, after that tap water and *EF* worms till the end of experiment period.

2. The cumulative amount of CO_2 produced during composting period was lower than evolved by burning wood. Thus, compost of wood is the best procedure to dispose of it which we can use the end product as a soil conditioner in extreme soils. Furthermore, disposed of wood by burning evolved high amount of CO_2 which it has a negative effect on the atmosphere by increasing global warming and consequently human, plant and animal activities.

3. Composts are variable materials. Differences in properties of the different compost types studied were mainly attributed to the input materials (or different ratios of input materials), the composting process, and the level of compost maturity.

4. The variation of wood compost properties implies management issues for their sustainable utilization in agriculture. Thus, compost management should depend on, and adjust according to the specific characteristics of each compost type and batch produced.

5. Wood composts should be applied to agriculture as they may contribute to the increase of soil organic matter level and potentially enhance nutrient availability to the crop.

6. There is evidence to suggest that due to compost variability, prior to application to agricultural land, composts should be analyzed for the following properties: heavy metal content, total N and C: N ratio, electrical conductivity, pH value and P content, OM and available nutrients, as they may influence soil quality parameters and subsequently crop and/or grass production.

7. Wood compost and/or vermicompost proved to be superior soil amendments to coal mine waste either in tertiary or quaternary soil. It can recommend that both types of grasses suitable for planting in both studied soils, with the higher rank recorded to Autoch grass.

8. Wood compost not only restores the soil physio-chemical structure, which has been destroyed during digging practices for collecting the coal, but at the same time also enhances the biological nutrient transformation in soils for sustainable land productivity.

9. In this research work the effects of a short term wood compost application on soil properties, grass production. The longer term effects of wood compost application need to be assessed, especially in terms of OM stability, N leaching potential as a large amount of organic N is being built up in the soil. Long term studies of the effects of using compost and ARK component in agriculture are necessary for the development of the optimum system for managing the utilization of wood compost for sustainable agriculture, which will ensure the environmental risk is minimized and the agronomic benefit is maximized.

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8. APPENDIX

8.1. First compost experiment

Table A.1: The weakly mean of temperature degree [^{o}C] produced during composting period

Water type	Mixing ratio	Infection worm	Duration (days)													
			Without infection				With infection									
			7	14	21	28	35	42	48	56	63	70	77	84	91	100
***QR* wood**																
Tap water	1WC:1LM	0	25.6	32.2	38.4	32.6	24.4	20.3	22.1	22.9	22.8	20.2	21.1	21.7	20.7	19.6
		EF	25.4	33	37.3	33.9	25.8	21.6	23.4	24.5	23.7	20.3	21.6	20.7	21.3	20.9
		DV	26	33	38.1	32	25.8	21.1	21.2	24	21.7	20.9	20.7	21.1	20.1	19.5
	1WC:3LM	0	26.4	33.6	40.6	31.8	24.6	20.4	22.3	23.5	22.7	20.1	21.2	21.8	21.4	21
		EF	26.2	34.9	41.9	33	26	21.7	22.8	25	23.6	20.3	21.7	20.8	20.3	19.6
		DV	26.7	35	40.6	31.1	26	21.1	21.4	24.2	21.6	20.8	20.8	21.1	20.9	19.7
Compost water	1WC:1LM	0	26.9	35.5	43	34.2	25.2	20.9	22.6	23.8	23	20.4	21.4	22	21.1	20
		EF	26.7	36.4	44.3	35.4	26.6	22.2	23.9	25.3	23.9	20.5	21.9	21	20.5	19.9
		DV	27.2	36.4	43.9	33.5	26.6	21.6	21.7	24.5	21.9	21.1	21	21.4	21.6	21.3
	1WC:3LM	0	27.8	38.3	47.2	35	26.1	21.5	22.9	24.4	23.4	20.8	21.8	21.1	20.7	20.4
		EF	27.5	38.1	46.1	36.4	27	22.8	23.6	25	24	20.9	22.3	22.8	21.6	20.5
		DV	27.9	38.3	46.8	36	27.3	22.2	22.3	25.1	23.4	21.5	21.4	20.7	22.1	21.8
***PS* wood**																
Tap water	1WC:1LM	0	23.4	26.7	30.9	25.2	20.3	18.9	19.1	20.9	19.9	18.3	18.3	18.3	18.7	19.3
		EF	23.8	27.3	31.5	24.3	19.9	20	19.8	22	21	19.4	18	17.3	17.1	17.2
		DV	24.1	27.7	30.8	24.9	19.3	17.9	18.8	19.9	20.4	18.8	18.8	18.8	18.6	18.7
	1WC:3LM	0	24.2	28.3	30.9	24.8	20.5	19	19.5	20.8	19.8	18.3	18.7	18.5	17.8	18.3
		EF	25	29.3	32.1	23.9	20.1	20.1	20.2	21.9	20.9	19.4	18.4	18.4	18.1	18.8
		DV	24.6	27.3	31.1	24.6	19.5	19	18.5	19.8	18.8	17.3	19.2	18.9	18.4	17.3
Compost water	1WC:1LM	0	24.8	29.7	33.3	27.2	21.1	19.5	20.3	21.1	20.1	18.5	18.2	17.6	18	18.6
		EF	25.2	28.7	34.1	26.3	20.7	20.6	21.4	22.2	21.2	19.6	18.6	18.6	18.4	19.1
		DV	25.5	30.7	33.8	27	20.1	18.5	19.3	20.1	19.1	17.5	19.1	19.1	18.6	17.6
	1WC:3LM	0	25.4	31.6	36.2	28.4	21.7	20.1	20.4	21.7	20.5	18.9	18.6	18.1	18.5	19.1
		EF	25.9	32.2	37.2	27.5	21.3	21.2	21.4	22.8	21.6	20	19	19.1	18.9	19.6
		DV	26.2	32.6	36.5	28.2	20.7	19.1	19.9	20.7	19.5	17.9	19.5	19.6	19.1	18.1

Data represent averages of three replicates

Table A.2: The weakly cumulative amount of CO_2 [g kg^{-1}] produced during composting period

Water type	Mixing ratio	Infection worm	Duration (days)													
			Without infection				With infection									
			7	14	21	28	35	42	48	56	63	70	77	84	91	100
***QR* wood**																
Tap water	1WC:1LM	0	47.3	80.8	102.7	82.6	58.5	51.7	45.0	44.6	41.3	31.0	16.4	15.5	14.5	14.4
		EF	54.3	78.8	104.6	88.7	76.8	70.7	55.8	53.8	56.0	60.3	34.3	21.3	17.5	17.5
		DV	50.3	85.8	105.5	85.6	72.5	61.4	64.1	55.7	50.8	53.9	28.0	19.8	15.4	15.3
	1WC:3LM	0	33.8	75.2	98.4	83.3	59.7	48.7	41.5	38.5	35.4	21.3	9.2	9.2	9.4	9.4
		EF	37.8	71.2	99.4	87.3	75.2	68.4	55.5	46.2	45.1	28.0	14.8	12.7	12.5	12.5
		DV	42.8	77.2	100.4	86.3	70.8	65.8	49.5	43.4	41.2	25.1	13.1	12.0	12.1	12.0
Compost water	1WC:1LM	0	58.0	80.2	116.5	97.2	67.7	57.7	51.6	48.5	47.1	37.1	23.9	17.9	15.9	15.9
		EF	62.0	85.2	111.5	99.1	80.8	80.0	65.5	65.2	61.6	61.4	38.9	25.2	18.5	18.4
		DV	66.0	88.2	117.5	100.1	74.2	75.2	62.8	60.4	58.4	57.4	35.2	20.1	16.9	16.8
	1WC:3LM	0	50.5	85.3	104.1	87.2	62.6	54.6	44.7	41.7	36.3	25.4	11.9	10.8	10.7	10.6
		EF	53.5	84.3	105.1	90.2	84.1	65.9	55.3	58.6	46.1	36.1	17.0	13.9	12.8	12.8
		DV	48.5	87.3	102.1	85.3	79.0	74.1	61.6	48.3	43.2	33.1	16.0	13.0	12.0	12.1
***PS* wood**																
Tap water	1WC:1LM	0	46.1	53.7	70.5	59.5	39.5	39.5	33.6	36.6	32.8	24.2	13.5	12.5	12.3	12.3
		EF	45.1	55.7	76.1	63.5	57.2	48.1	40.0	39.0	39.9	29.9	15.7	14.7	13.9	13.8
		DV	42.1	51.7	73.5	60.5	47.5	45.5	43.7	43.6	36.9	26.9	14.8	13.5	13.5	13.4
	1WC:3LM	0	33.0	55.1	72.0	68.9	46.0	34.0	29.4	29.3	25.5	12.4	7.8	7.8	6.7	6.6
		EF	39.0	56.1	76.0	66.9	51.6	46.6	35.4	34.8	32.3	20.3	8.6	8.6	8.6	8.6
		DV	35.0	53.1	80.0	63.9	49.0	43.9	31.1	30.4	29.4	16.3	8.6	8.5	8.5	8.5
Compost water	1WC:1LM	0	48.9	65.0	85.9	71.9	43.8	42.8	38.6	38.4	36.3	28.4	15.6	14.8	13.3	13.4
		EF	46.9	67.0	88.9	70.9	64.2	52.2	44.8	45.0	44.0	35.0	21.8	17.0	15.3	15.2
		DV	49.9	64.0	82.9	69.0	53.6	47.6	43.1	43.7	42.7	31.8	18.6	16.0	14.0	14.0
	1WC:3LM	0	36.0	65.8	75.2	66.2	46.2	36.2	29.6	29.5	25.6	20.6	8.0	8.0	8.7	8.6
		EF	41.0	63.8	77.2	65.2	60.2	49.6	38.7	37.9	32.9	23.8	10.7	9.8	9.4	9.3
		DV	39.0	69.8	73.2	69.2	55.5	46.5	36.0	33.0	32.2	22.9	9.1	9.3	9.0	9.0

Data represent averages of three replicates

Table A.3: Theoretical (Th) amount of CO_2 [g kg^{-1}] under different studied wood mixtures

Mixing ratio	$ThCO_2$ [g kg^{-1}]	
	QR	*PS*
1WC:1LM	1162.70	1120.17
1WC:3LM	835.27	825.37

Table A.4: The cumulative amount of CO_2 [g kg^{-1}] produced during composting period and the other evolved by burning wood

Water type	Mixing ratio	infection worm	Duration (days)													
			Without infection				With infection									
			7	14	21	28	35	42	48	56	63	70	77	84	91	100
			***QR* wood**													
Tap water	1WC:1LM	0	47.3	128.1	230.9	313.5	372.0	423.6	468.6	513.2	554.4	585.5	601.9	617.5	632.0	646.4
		EF	54.3	133.2	237.8	326.5	403.3	474.0	529.8	583.6	639.7	690.0	724.3	745.6	763.1	780.6
		DV	50.3	136.2	241.7	327.3	399.8	461.2	525.3	581.0	631.8	675.7	703.6	723.5	738.8	754.2
	1WC:3LM	0	33.8	109.0	207.3	290.6	350.3	399.0	440.5	479.0	514.4	535.7	544.9	554.2	563.6	573.0
		EF	37.8	109.0	208.3	295.6	370.9	439.3	494.8	541.0	586.1	614.1	628.9	641.6	654.1	666.6
		DV	42.8	120.0	220.3	306.7	377.5	443.3	492.8	536.2	577.3	602.4	615.5	627.6	639.7	651.7
Compost water	1WC:1LM	0	58.0	138.2	254.6	351.8	419.5	477.2	528.8	577.3	624.4	661.5	685.4	703.3	719.3	735.2
		EF	62.0	147.2	258.6	357.8	438.6	518.7	584.1	649.4	711.0	772.4	811.3	836.6	855.0	873.4
		DV	66.0	154.2	271.6	371.8	446.0	521.2	584.0	644.5	702.9	760.3	795.5	815.6	832.5	849.3
	1WC:3LM	0	50.5	135.8	239.9	327.1	389.7	444.3	489.0	530.7	567.0	592.4	604.3	615.1	625.8	636.4
		EF	53.5	137.8	242.9	333.1	417.2	483.1	538.4	597.1	643.2	679.3	696.3	710.2	723.1	735.9
		DV	48.5	135.8	237.9	323.1	402.1	476.2	537.8	586.1	629.3	662.4	678.4	691.4	703.4	715.5
			CO_2 produced by burning *QR* wood [g kg^{-1} wood]													1860.8
			***PS* wood**													
Tap water	1WC:1LM	0	46.1	99.9	170.4	229.9	269.4	309.0	342.6	379.2	412.0	436.2	449.7	462.2	474.5	486.8
		EF	45.1	100.9	177.0	240.5	297.7	345.8	385.8	424.8	464.6	494.5	510.2	524.9	538.8	552.6
		DV	42.1	93.9	167.4	227.9	275.4	320.9	364.6	408.3	445.2	472.1	486.8	500.4	513.9	527.2
	1WC:3LM	0	33.0	88.1	160.1	229.0	275.1	309.1	338.5	367.8	393.3	405.7	413.5	421.3	428.0	434.6
		EF	39.0	95.1	171.1	238.0	289.7	336.3	371.7	406.5	438.9	459.2	467.7	476.3	484.9	493.5
		DV	35.0	88.1	168.1	232.0	281.0	324.9	356.0	386.4	415.8	432.1	440.7	449.2	457.8	466.3
Compost water	1WC:1LM	0	48.9	113.9	199.8	271.7	315.5	358.3	396.9	435.4	471.7	500.1	515.7	530.5	543.8	557.2
		EF	46.9	113.9	202.8	273.7	337.8	390.1	434.8	479.8	523.8	558.8	580.7	597.7	612.9	628.2
		DV	49.9	113.9	196.8	265.8	319.4	367.0	410.1	453.8	496.6	528.4	547.0	563.0	577.1	591.1
	1WC:3LM	0	36.0	101.8	177.0	243.2	289.4	325.6	355.2	384.8	410.4	431.0	439.0	447.1	455.8	464.4
		EF	41.0	104.8	182.0	247.2	307.4	357.0	395.7	433.6	466.5	490.3	501.0	510.7	520.1	529.4
		DV	39.0	108.8	182.0	251.2	306.7	353.3	389.3	422.3	454.5	477.4	486.5	495.8	504.8	513.8
			CO_2 produced by burning *PS* wood [g kg^{-1} wood]													1860.1

Data represent averages of three replicates

Table A.5: Degree of biodegradation [%] during composting of different studied wood treatments

Water type	Mixing ratio	Infection worm	Duration (days)													
			Without infection				With infection									
			7	14	21	28	35	42	48	56	63	70	77	84	91	100
			***QR* wood**													
Tap water	1WC:1LM	0	4.1	11.0	19.9	27.0	32.0	36.4	40.3	44.1	47.7	50.4	51.8	53.1	54.4	55.6
		EF	4.7	11.5	20.5	28.1	34.7	40.8	45.6	50.2	55.0	59.3	62.3	64.1	65.6	67.1
		DV	4.3	11.7	20.8	28.2	34.4	39.7	45.2	50.0	54.3	58.1	60.5	62.2	63.5	64.9
	1WC:3LM	0	4.0	13.1	24.8	34.8	41.9	47.8	52.7	57.4	61.6	64.1	65.2	66.3	67.5	68.6
		EF	4.5	13.0	24.9	35.4	44.4	52.6	59.2	64.8	70.2	73.5	75.3	76.8	78.3	79.8
		DV	5.1	14.4	26.4	36.7	45.2	53.1	59.0	64.2	69.1	72.1	73.7	75.1	76.6	78.0
Compost water	1WC:1LM	0	5.0	11.9	21.9	30.3	36.1	41.0	45.5	49.7	53.7	56.9	59.0	60.5	61.9	63.2
		EF	5.3	12.7	22.2	30.8	37.7	44.6	50.2	55.9	61.2	66.4	69.8	72.0	73.5	75.1
		DV	5.7	13.3	23.4	32.0	38.4	44.8	50.2	55.4	60.5	65.4	68.4	70.2	71.6	73.1
	1WC:3LM	0	6.0	16.3	28.7	39.2	46.7	53.2	58.6	63.5	67.9	70.9	72.4	73.7	74.9	76.2
		EF	6.4	16.5	29.1	39.9	50.0	57.8	64.5	71.5	77.0	81.3	83.4	85.0	86.6	88.1
		DV	5.8	16.3	28.5	38.7	48.1	57.0	64.4	70.2	75.3	79.3	81.2	82.8	84.2	85.7
			***PS* wood**													
Tap water	1WC:1LM	0	4.1	8.9	15.2	20.5	24.1	27.6	30.6	33.9	36.8	38.9	40.1	41.3	42.4	43.5
		EF	4.0	9.0	15.8	21.5	26.6	30.9	34.4	37.9	41.5	44.2	45.6	46.9	48.1	49.3
		DV	3.8	8.4	14.9	20.4	24.6	28.7	32.6	36.5	39.7	42.1	43.5	44.7	45.9	47.1
	1WC:3LM	0	4.0	10.7	19.4	27.8	33.3	37.5	41.0	44.6	47.7	49.2	50.1	51.1	51.9	52.7
		EF	4.7	11.5	20.7	28.8	35.1	40.7	45.0	49.3	53.2	55.6	56.7	57.7	58.8	59.8
		DV	4.2	10.7	20.4	28.1	34.0	39.4	43.1	46.8	50.4	52.4	53.4	54.4	55.5	56.5
Compost water	1WC:1LM	0	4.4	10.2	17.8	24.3	28.2	32.0	35.4	38.9	42.1	44.6	46.0	47.4	48.6	49.7
		EF	4.2	10.2	18.1	24.4	30.2	34.8	38.8	42.8	46.8	49.9	51.8	53.4	54.7	56.1
		DV	4.5	10.2	17.6	23.7	28.5	32.8	36.6	40.5	44.3	47.2	48.8	50.3	51.5	52.8
	1WC:3LM	0	4.4	12.3	21.5	29.5	35.1	39.5	43.0	46.6	49.7	52.2	53.2	54.2	55.2	56.3
		EF	5.0	12.7	22.1	30.0	37.2	43.3	47.9	52.5	56.5	59.4	60.7	61.9	63.0	64.1
		DV	4.7	13.2	22.1	30.4	37.2	42.8	47.2	51.2	55.1	57.8	58.9	60.1	61.2	62.3

Data represent averages of three replicates

Table A.6: Organic matter content [%] during composting of different studied wood treatments

Water type	Mixing ratio	Infection worm	***QR* wood**								***PS* wood**							
			Duration (days)								Duration (days)							
			Without infection			With infection					Without infection			With infection				
			7	14	28	42	56	70	84	100	7	14	28	42	56	70	84	100
Tap water	1WC:1LM	0.0	66.8	62.6	58.8	57.6	56.9	55.0	53.6	52.6	66.7	65.3	65.3	65.1	64.8	64.3	62.8	61.4
		EF	65.9	61.5	59.8	52.2	43.4	39.6	39.2	39.1	65.7	65.8	65.4	62.5	62.2	61.3	55.8	55.9
		DV	64.8	60.5	57.7	55.2	49.8	46.2	43.0	42.2	66.1	65.7	65.4	63.6	62.9	63.6	60.0	58.6
	1WC:3LM	0.0	42.2	40.3	34.2	33.2	30.9	30.3	29.0	26.8	43.3	42.5	37.9	37.5	37.4	37.4	37.2	37.2
		EF	43.5	42.3	35.2	27.5	23.0	20.2	20.0	19.3	44.2	43.4	39.0	36.3	36.2	35.0	34.5	34.2
		DV	42.7	41.2	33.3	28.5	25.6	23.3	22.9	22.5	42.9	41.4	36.9	36.8	36.6	36.7	36.4	36.2
Compost water	1WC:1LM	0.0	65.3	58.0	52.3	48.2	45.9	42.6	42.3	40.7	65.8	63.6	59.8	59.1	58.1	56.8	56.8	55.5
		EF	64.3	59.0	51.3	42.2	34.9	30.6	29.3	29.1	64.3	62.0	58.1	56.5	56.1	54.2	53.8	52.5
		DV	66.0	57.0	52.2	43.8	38.6	35.6	35.0	34.6	65.3	63.0	58.8	57.9	57.6	55.7	55.3	54.8
	1WC:3LM	0.0	44.4	39.2	33.7	31.8	28.4	28.1	26.1	24.4	42.8	40.6	38.9	38.1	37.1	36.8	36.4	36.3
		EF	42.5	38.5	34.6	24.5	21.0	18.5	18.3	18.3	43.3	42.6	39.9	36.1	35.0	34.5	33.4	32.3
		DV	41.4	37.5	33.6	26.5	24.6	22.3	21.9	21.5	42.1	40.1	38.3	37.9	36.8	34.7	34.8	34.1

Data represent averages of three replicates

Table A.7: Total organic carbon content [%] during composting of different studied wood treatments

Water type	Mixing ratio	Infection worm	***QR* wood**								***PS* wood**							
			Duration (days)								Duration (days)							
			Without infection			With infection					Without infection			With infection				
			7	14	28	42	56	70	84	100	7	14	28	42	56	70	84	100
Tap water	1WC:1LM	0.0	38.7	36.3	34.1	33.4	33.0	31.9	31.1	30.5	38.7	37.9	37.9	37.7	37.6	37.3	36.5	35.6
		EF	38.2	35.7	34.7	30.3	25.2	22.9	22.7	22.7	38.1	38.2	37.9	36.3	36.1	35.5	32.4	32.4
		DV	37.6	35.1	33.5	32.0	28.9	26.8	24.9	24.5	38.4	38.1	37.9	36.9	36.5	36.9	34.8	34.0
	1WC:3LM	0.0	24.5	23.4	19.9	19.2	17.9	17.6	16.8	15.6	25.1	24.6	22.0	21.8	21.7	21.7	21.6	21.6
		EF	25.3	24.5	20.4	15.9	13.3	11.7	11.6	11.2	25.6	25.2	22.6	21.1	21.0	20.3	20.0	19.8
		DV	24.8	23.9	19.3	16.5	14.9	13.5	13.3	13.1	24.9	24.0	21.4	21.3	21.2	21.3	21.1	21.0
Compost water	1WC:1LM	0.0	37.9	33.6	30.3	27.9	26.6	24.7	24.6	23.6	38.2	36.9	34.7	34.3	33.7	33.0	32.9	32.2
		EF	37.3	34.2	29.7	24.5	20.2	17.8	17.0	16.9	37.3	36.0	33.7	32.8	32.5	31.5	31.2	30.5
		DV	38.3	33.0	30.3	25.4	22.4	20.7	20.3	20.1	37.9	36.6	34.1	33.6	33.4	32.3	32.1	31.8
	1WC:3LM	0.0	25.8	22.7	19.5	18.4	16.5	16.3	15.2	14.2	24.8	23.5	22.6	22.1	21.5	21.4	21.1	21.1
		EF	24.6	22.4	20.1	14.2	12.2	10.7	10.6	10.6	25.1	24.7	23.2	21.0	20.3	20.0	19.4	18.7
		DV	24.0	21.8	19.5	15.3	14.3	12.9	12.7	12.5	24.4	23.3	22.2	22.0	21.4	20.2	20.2	19.8

Data represent averages of three replicates

Table A.8: Total extractable carbon content [%] during composting of different studied wood treatments

Water type	Mixing ratio	Infection worm	***QR* wood**								***PS* wood**							
			Duration (days)								Duration (days)							
			Without infection			With infection					Without infection			With infection				
			7	14	28	42	56	70	84	100	7	14	28	42	56	70	84	100
Tap water	1WC:1LM	0.0	21.3	21.1	17.9	17.6	17.3	16.8	16.4	16.0	19.3	19.9	19.9	19.8	19.7	19.7	19.6	19.2
		EF	21.1	20.7	18.2	15.9	14.3	13.2	13.0	13.0	20.0	20.0	19.9	18.9	18.9	18.8	18.6	18.2
		DV	21.7	20.4	17.6	16.9	16.2	14.2	14.2	13.9	21.1	20.0	19.7	19.5	19.3	19.3	19.2	18.9
	1WC:3LM	0.0	15.7	14.0	10.8	10.7	10.6	10.4	10.2	10.1	14.2	14.3	13.6	13.3	12.9	12.8	12.7	12.6
		EF	15.2	14.7	11.2	9.3	8.7	8.8	8.6	8.5	14.4	14.1	14.0	12.5	12.1	11.9	11.5	11.0
		DV	15.9	14.4	10.5	9.7	9.7	9.8	9.7	9.5	14.9	14.1	13.4	13.3	12.8	12.0	12.0	11.7
Compost water	1WC:1LM	0.0	20.5	22.0	17.0	16.7	15.9	15.9	15.8	15.3	20.7	20.0	20.7	20.4	20.1	19.6	19.1	18.7
		EF	21.2	21.4	17.8	15.7	13.2	12.7	12.3	12.2	19.2	19.4	20.1	19.5	19.4	18.7	17.0	17.0
		DV	20.7	21.7	18.1	16.2	14.5	13.4	13.2	13.1	21.5	20.7	20.3	20.0	19.9	19.4	18.3	18.0
	1WC:3LM	0.0	15.8	14.7	11.6	10.8	10.5	9.4	9.6	9.6	14.1	13.8	12.2	12.0	12.0	12.0	11.9	11.9
		EF	15.0	14.5	12.0	9.2	9.0	8.7	8.4	8.3	14.4	14.2	12.5	11.5	11.4	11.1	10.8	10.5
		DV	15.6	14.1	11.6	9.8	9.4	8.8	8.8	8.8	14.0	13.4	11.8	11.7	11.7	11.7	11.6	11.5

Data represent averages of three replicates

Table A.9: Humic acid content [%] during composting of different studied wood treatments

Water type	Mixing ratio	Infection worm	***QR* wood**								***PS* wood**							
			Duration (days)								Duration (days)							
			Without infection			With infection					Without infection			With infection				
			7	14	28	42	56	70	84	100	7	14	28	42	56	70	84	100
Tap water	1WC:1LM	0.0	5.2	5.2	5.3	5.6	5.6	5.4	5.2	5.2	3.9	4.0	4.1	4.2	4.2	4.1	3.2	3.2
		EF	4.9	5.3	5.5	5.9	6.1	5.7	5.8	6.1	3.9	4.1	4.2	4.4	4.5	4.4	3.8	4.3
		DV	4.8	5.4	5.6	5.7	5.8	5.6	5.4	5.5	3.7	3.9	4.0	4.6	4.4	4.2	3.5	3.5
	1WC:3LM	0.0	3.8	3.8	3.9	4.2	4.3	4.0	3.8	3.9	3.1	3.1	3.2	3.3	3.4	3.2	2.3	2.9
		EF	3.5	4.1	4.1	4.4	4.8	4.5	4.4	4.7	3.0	3.3	3.4	3.7	3.8	3.6	2.8	3.1
		DV	3.4	3.9	3.8	4.6	4.5	4.4	3.9	4.3	2.9	3.0	3.2	3.6	3.6	3.4	2.6	3.4
Compost water	1WC:1LM	0.0	5.9	5.9	6.0	6.3	6.3	6.1	5.9	5.9	4.6	4.7	4.7	4.7	4.8	4.8	3.9	4.5
		EF	5.6	6.1	6.2	6.4	6.8	6.5	6.5	6.8	4.6	4.8	4.9	5.0	5.2	5.1	4.3	4.6
		DV	5.5	6.0	5.8	6.6	6.5	6.4	6.0	6.2	4.4	4.6	4.7	4.8	4.9	4.9	4.2	4.8
	1WC:3LM	0.0	4.6	4.6	4.7	5.0	5.1	4.8	4.6	4.7	3.9	3.9	4.0	4.1	4.2	4.0	3.1	3.7
		EF	4.3	4.9	4.9	5.2	5.6	5.2	5.2	5.3	3.8	4.1	4.2	4.5	4.4	4.2	3.6	3.9
		DV	4.2	4.7	5.1	5.4	5.3	5.3	4.7	5.1	3.7	3.8	4.0	4.4	4.6	4.4	3.4	4.2

Data represent averages of three replicates

Table A.10: Fulvic acid content [%] during composting of different studied wood treatments

Water type	Mixing ratio	Infection worm	***QR* wood**								***PS* wood**							
			Duration (days)								Duration (days)							
			Without infection			With infection					Without infection			With infection				
			7	14	28	42	56	70	84	100	7	14	28	42	56	70	84	100
Tap water	1WC:1LM	0.0	2.0	2.2	2.2	2.3	2.3	2.4	2.1	1.7	1.4	1.5	1.5	1.6	1.6	1.3	1.3	1.2
		EF	2.1	2.1	2.2	2.5	2.6	2.9	2.5	2.3	1.3	1.4	1.4	1.9	2.1	2.1	1.8	1.6
		DV	2.1	2.2	2.2	2.4	2.4	2.7	2.2	2.1	1.5	1.6	1.5	1.8	2.0	2.1	1.6	1.4
	1WC:3LM	0.0	1.4	1.5	1.6	1.6	1.7	1.7	1.6	1.4	1.2	1.2	1.2	1.2	1.3	1.3	1.1	1.0
		EF	1.5	1.5	1.6	2.0	2.2	2.3	2.0	1.8	1.0	1.1	1.1	1.4	1.4	1.6	1.4	1.3
		DV	1.3	1.4	1.6	1.9	2.2	2.3	1.7	1.7	1.2	1.1	1.2	1.3	1.5	1.5	1.3	1.3
Compost water	1WC:1LM	0.0	2.2	2.4	2.4	2.6	2.6	2.6	2.4	2.1	1.6	1.7	1.8	1.9	1.9	1.6	1.6	1.5
		EF	2.4	2.4	2.4	2.8	3.2	3.4	2.9	2.7	1.7	1.7	1.8	2.2	2.3	2.4	2.1	1.9
		DV	2.1	2.3	2.5	2.8	3.2	3.2	2.5	2.4	1.6	1.8	1.8	2.2	2.2	2.3	1.9	1.6
	1WC:3LM	0.0	1.6	1.7	1.9	2.0	2.0	2.0	1.8	1.7	1.2	1.3	1.3	1.4	1.3	1.4	1.2	1.1
		EF	1.6	1.8	1.8	2.3	2.5	2.6	2.4	2.1	1.1	1.2	1.4	1.6	1.7	1.8	1.6	1.3
		DV	1.4	1.8	1.8	2.2	2.3	2.5	2.2	2.0	1.2	1.2	1.2	1.4	1.7	1.7	1.4	1.4

Data represent averages of three replicates

Table A.11: Degree of humification [%] during composting of different studied wood treatments

Water type	Mixing ratio	Infection worm	***QR* wood**								***PS* wood**							
			Duration (days)								Duration (days)							
			Without infection			With infection					Without infection			With infection				
			7	14	28	42	56	70	84	100	7	14	28	42	56	70	84	100
Tap water	1WC:1LM	0.0	34.9	33.5	43.8	47.1	50.0	48.5	45.6	45.6	25.7	27.4	27.0	28.1	29.2	27.7	23.7	23.4
		EF	32.9	34.6	43.2	53.9	66.3	67.6	67.2	68.3	27.1	28.2	28.1	32.5	34.3	35.2	32.6	34.7
		DV	33.3	35.2	43.3	49.9	57.0	61.7	57.8	57.6	24.3	26.3	27.0	31.9	32.1	32.5	27.8	27.5
	1WC:3LM	0.0	33.3	37.9	50.6	54.4	56.7	55.0	52.5	52.5	29.8	30.2	31.7	34.1	35.8	35.4	27.3	30.6
		EF	33.0	37.9	51.2	68.1	80.2	76.5	74.5	76.4	28.2	30.9	32.0	40.6	42.7	43.5	36.1	39.1
		DV	29.7	37.0	51.0	66.5	68.9	67.2	58.3	62.3	27.5	29.3	32.1	36.5	39.5	40.3	32.8	39.6
Compost water	1WC:1LM	0.0	37.9	39.2	46.7	50.4	51.6	51.6	50.2	50.5	32.5	32.3	32.8	33.3	34.2	32.7	28.2	30.8
		EF	37.8	41.2	47.1	57.8	70.2	75.2	71.8	72.6	31.3	32.4	33.7	37.9	39.7	40.2	34.4	35.9
		DV	35.0	40.4	47.1	55.9	59.9	67.8	60.0	61.3	28.6	31.8	32.8	36.0	36.7	37.3	31.9	33.7
	1WC:3LM	0.0	38.9	42.8	56.8	64.5	67.5	72.5	66.1	66.7	35.9	37.7	43.3	45.7	46.0	45.2	36.8	40.5
		EF	39.4	45.8	56.2	81.1	89.9	89.0	90.5	90.2	34.3	37.4	44.1	53.1	53.0	53.2	47.5	49.2
		DV	36.2	46.5	59.6	77.5	80.6	87.9	78.9	80.0	34.7	37.3	43.5	49.2	53.7	51.6	41.9	48.2

Data represent averages of three replicates

Table A.12: Humification rate [%] during composting of different studied wood treatments

Water type	Mixing ratio	Infection worm	***QR* wood**								***PS* wood**							
			Duration (days)								Duration (days)							
			Without infection			With infection					Without infection			With infection				
			7	14	28	42	56	70	84	100	7	14	28	42	56	70	84	100
Tap water	1WC:1LM	0.0	18.5	20.3	21.8	23.5	24.1	24.1	23.2	22.8	13.8	14.4	14.7	15.2	15.6	14.5	12.4	12.3
		EF	18.2	20.7	22.1	27.9	34.6	37.5	36.4	36.8	13.7	14.4	14.9	17.5	18.4	18.5	17.1	18.2
		DV	18.4	21.7	23.4	25.3	28.5	30.9	30.6	30.8	13.6	14.3	14.5	17.3	17.5	17.0	14.6	14.5
	1WC:3LM	0.0	21.4	22.7	27.5	30.4	33.5	32.5	31.8	34.1	16.8	17.5	19.7	20.9	21.3	20.9	16.0	17.9
		EF	19.8	22.8	28.0	39.9	52.4	57.5	55.4	58.0	15.8	17.3	19.9	24.2	24.6	25.6	20.7	21.8
		DV	19.1	22.2	27.6	39.2	44.9	48.9	42.5	45.5	16.4	17.2	20.1	22.6	23.9	22.7	18.7	22.2
Compost water	1WC:1LM	0.0	21.3	24.6	27.6	31.6	33.7	35.1	33.4	34.1	16.4	17.4	18.8	19.2	20.0	19.5	16.8	18.4
		EF	21.3	25.0	28.8	37.7	49.7	55.7	55.0	55.9	16.8	18.0	19.9	21.9	23.1	24.0	20.5	21.4
		DV	19.9	25.0	27.3	37.0	43.4	46.5	41.9	42.5	15.9	17.4	18.9	20.9	21.3	22.2	19.1	20.1
	1WC:3LM	0.0	23.9	27.8	33.7	37.9	43.1	41.8	41.9	45.0	20.4	22.2	23.3	24.8	25.6	25.3	20.7	22.9
		EF	24.0	29.7	33.5	52.6	66.4	72.2	71.7	70.1	19.7	21.4	23.9	29.1	29.9	29.5	26.5	27.6
		DV	23.5	30.1	35.3	49.3	53.3	59.9	54.6	56.5	19.9	21.5	23.1	26.2	29.3	30.0	24.1	28.1

Data represent averages of three replicate

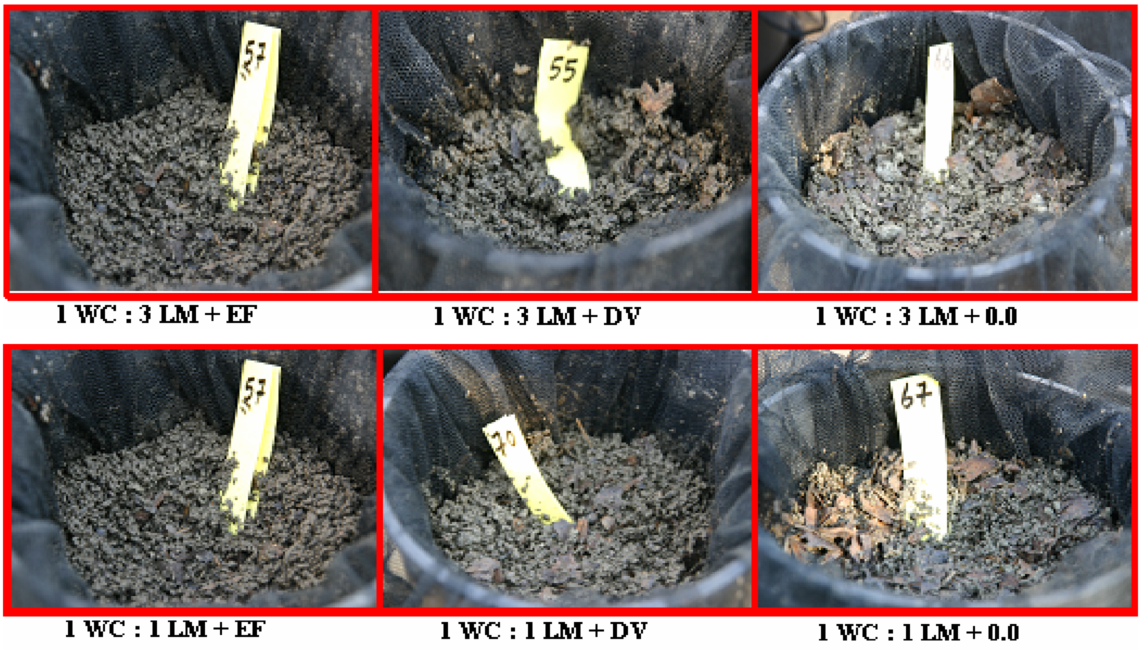
Table A.13: Humification index during composting of different studied wood treatments

Water type	Mixing ratio	Infection worm	***QR* wood**								***PS* wood**							
			Duration (days)								Duration (days)							
			Without infection			With infection					Without infection			With infection				
			7	14	28	42	56	70	84	100	7	14	28	42	56	70	84	100
Tap water	1WC:1LM	0.0	1.98	1.86	1.42	1.24	1.18	1.18	1.27	1.29	2.63	2.64	2.56	2.45	2.37	2.63	3.33	3.38
		EF	2.02	1.81	1.37	0.89	0.64	0.53	0.58	0.56	2.84	2.65	2.53	1.98	1.85	1.86	2.35	2.08
		DV	2.15	1.68	1.25	1.08	0.97	0.71	0.86	0.85	3.04	2.66	2.59	2.05	2.03	2.07	2.79	2.84
	1WC:3LM	0.0	2.01	1.64	0.98	0.84	0.76	0.82	0.91	0.91	2.36	2.31	2.15	1.94	1.79	1.82	2.67	2.27
		EF	2.03	1.64	0.95	0.47	0.25	0.31	0.34	0.31	2.55	2.23	2.12	1.46	1.34	1.30	1.77	1.56
		DV	2.37	1.70	0.96	0.50	0.45	0.49	0.72	0.61	2.64	2.41	2.12	1.74	1.53	1.48	2.05	1.52
Compost water	1WC:1LM	0.0	1.54	1.66	1.03	0.88	0.78	0.83	0.93	0.90	2.31	2.11	2.17	2.10	1.97	2.05	2.46	2.16
		EF	1.66	1.50	1.07	0.70	0.31	0.29	0.31	0.29	2.06	2.00	1.99	1.73	1.58	1.47	1.67	1.61
		DV	1.73	1.63	1.18	0.72	0.49	0.40	0.55	0.53	2.57	2.26	2.15	1.85	1.80	1.69	1.98	1.81
	1WC:3LM	0.0	1.57	1.33	0.76	0.55	0.48	0.38	0.51	0.50	1.79	1.65	1.31	1.19	1.18	1.21	1.72	1.47
		EF	1.54	1.18	0.78	0.23	0.11	0.12	0.11	0.11	1.92	1.68	1.27	0.89	0.89	0.88	1.11	1.03
		DV	1.76	1.15	0.68	0.29	0.24	0.14	0.27	0.25	1.88	1.68	1.30	1.03	0.86	0.94	1.39	1.08

Data represent averages of three replicates

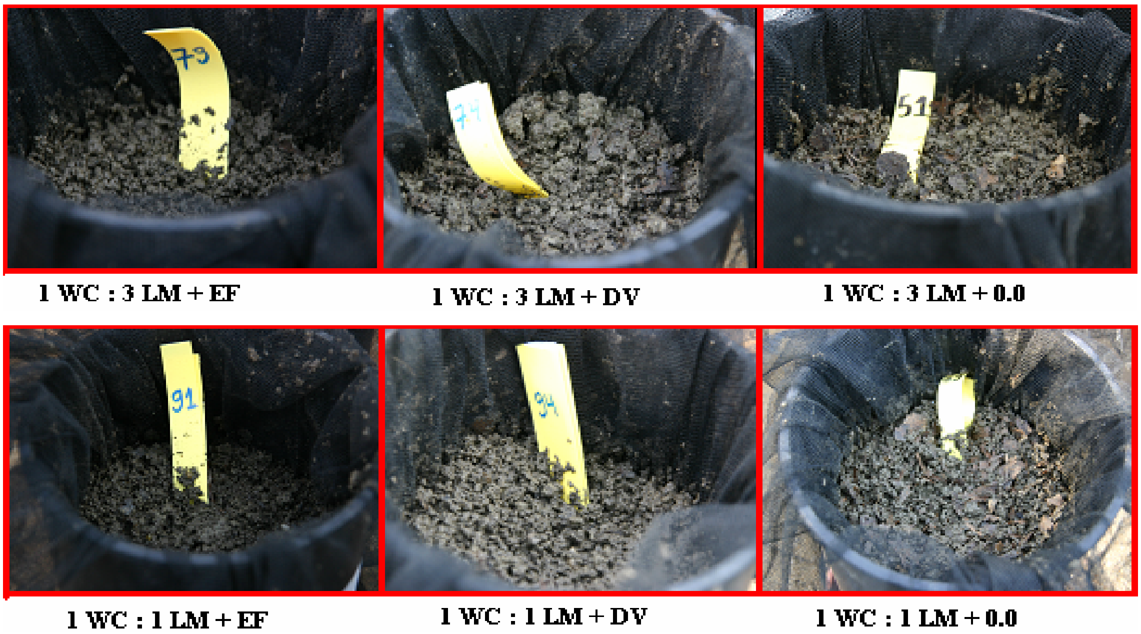
The treatments of *Quercus rubra* wood compost **The treatments of *Pinus sylvestris* wood compost**

Fig. A. 1: Design of the first compost experiment at the beginning (August 2007)



1 WC : 3 LM + EF
1 WC : 3 LM + DV
1 WC : 3 LM + 0.0
1 WC : 1 LM + EF
1 WC : 1 LM + DV
1 WC : 1 LM + 0.0

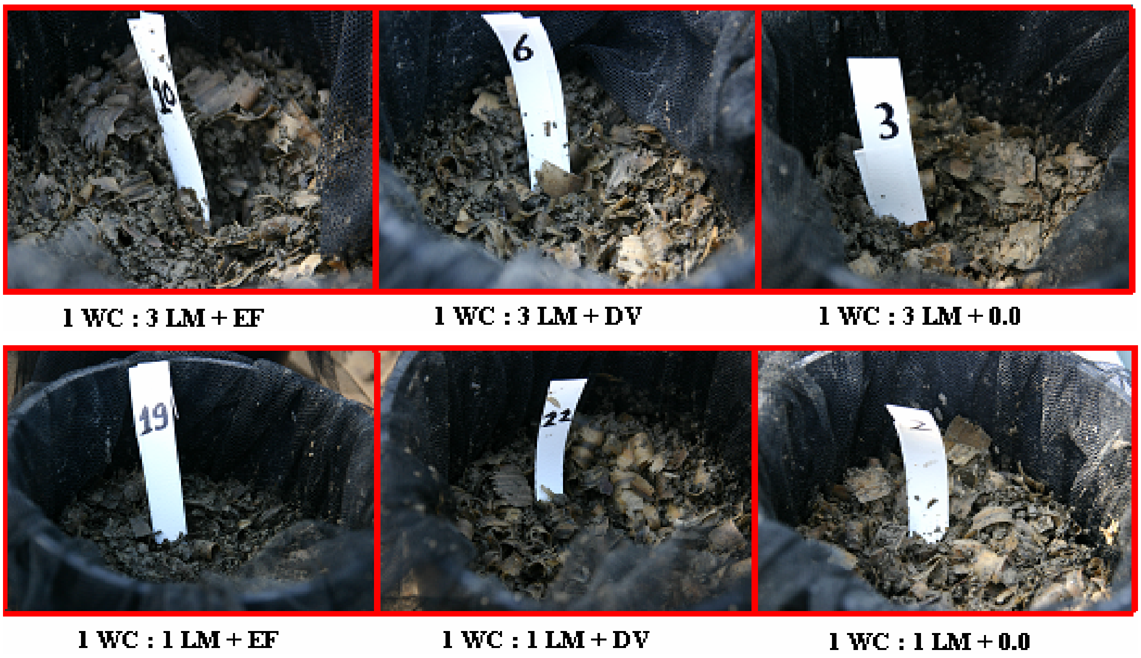
A. Tap water treatments



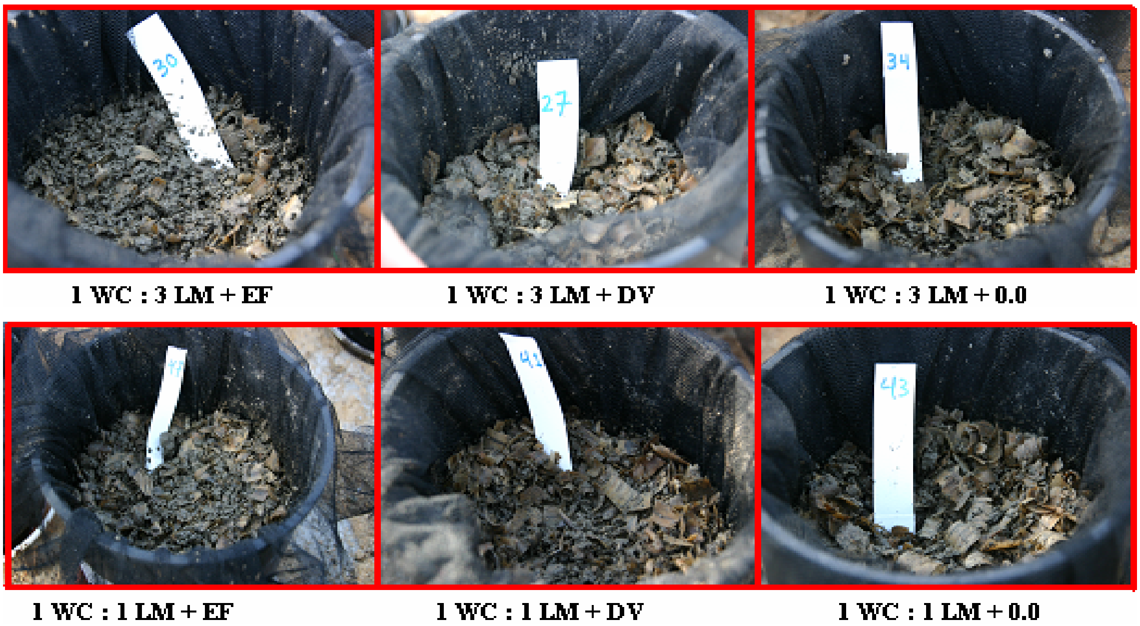
1 WC : 3 LM + EF
1 WC : 3 LM + DV
1 WC : 3 LM + 0.0
1 WC : 1 LM + EF
1 WC : 1 LM + DV
1 WC : 1 LM + 0.0

B. Compost water treatments

Fig. A. 2: The treatments of *Quercus rubra* wood compost at the end of experiment (November 2007)



A. **Tap water treatments**



B. **Compost water treatments**

Fig. A. 3: The treatments of *Pinus sylvestris* wood compost at the end of experiment (November 2007)

8.2. Second compost experiment

Table A.14: The weakly mean of temperature degree [^{0}C] produced during composting period

Mixing ratio	Water type	Infection worm	Duration (days)													
			7	14	21	28	35	42	48	56	63	70	77	84	91	100
1WC:2LM	C	0.0	25.7	37.7	45.6	36.7	29.7	30.8	30.5	30.4	31.4	27.6	25.2	24.3	24.5	22.5
	T	0.0	25.2	36.2	44.7	35.5	27.0	22.9	23.7	23.9	23.9	21.4	22.9	22.0	21.8	21.0
	T	*EF*	25.8	36.4	44.7	35.3	26.4	21.6	22.4	24.2	23.9	21.1	21.7	21.1	20.9	20.7
1WC:2HM	C	0.0	31.2	43.5	52.3	42.2	34.0	35.4	32.9	33.8	33.5	30.7	28.1	27.0	26.6	25.1
	T	0.0	30.8	43.5	52.1	42.8	33.5	27.6	28.6	28.6	30.2	28.4	28.7	27.8	28.1	25.5
	T	*EF*	31.2	43.5	52.3	42.5	33.3	26.4	29.3	30.2	29.0	27.7	30.5	26.8	25.3	24.8
WC:1LM:1HM	C	0.0	27.4	39.7	47.6	38.7	32.3	33.7	31.8	32.6	32.4	29.2	27.2	25.6	25.7	24.3
	T	0.0	27.5	39.6	47.4	38.7	29.5	24.0	25.3	26.4	25.4	23.4	24.9	23.8	22.9	22.9
	T	*EF*	28.0	38.8	47.4	37.3	28.4	24.6	25.3	26.2	26.4	23.1	23.7	23.3	23.8	22.8

Data represent averages of three replicates

C= compost water all composting period, T= Tap water after one month compost water

Table A.15: The weakly cumulative amount of CO_2 [g kg^{-1}] produced during composting period

Mixing ratio	Water type	Infection worm	Duration (days)													
			7	14	21	28	35	42	48	56	63	70	77	84	91	100
1WC:2LM	C	0.0	46.0	76.7	101.3	83.4	79.8	65.1	56.8	46.0	42.3	36.0	26.7	19.0	15.3	16.0
	T	0.0	44.2	75.7	102.3	84.7	70.2	53.2	48.2	37.1	41.7	32.2	20.4	16.4	13.2	12.6
	T	*EF*	47.7	77.7	100.3	82.2	73.5	68.0	57.4	46.9	46.9	45.8	36.0	20.6	16.5	16.3
1WC:2HM	C	0.0	86.1	123.9	130.9	121.6	86.9	92.7	85.9	73.2	70.4	55.1	37.3	25.1	18.4	18.6
	T	0.0	84.4	124.9	132.4	122.3	85.3	86.3	83.3	72.2	68.8	42.4	27.5	19.5	15.3	14.7
	T	*EF*	87.8	126.9	129.4	120.8	91.6	95.1	85.5	82.1	75.0	63.9	43.1	27.7	21.6	21.4
WC:1LM:1HM	C	0.0	55.0	95.8	121.6	101.5	81.4	70.9	65.3	54.6	61.4	50.1	32.0	21.5	16.9	17.3
	T	0.0	54.3	94.8	122.8	103.5	77.2	69.2	62.2	48.2	51.8	35.3	25.0	18.4	14.2	13.2
	T	*EF*	57.8	96.8	121.3	101.5	80.5	73.5	65.5	53.5	64.0	58.8	37.0	23.6	18.6	18.4

Data represent averages of three replicates

C= compost water all composting period, T= Tap water after one month compost water

Table A.16: Theoretical (Th) amount of CO_2 [g kg^{-1}] under different studied wood mixtures

Mixing ratio	$ThCO_2$ [g kg^{-1}]
1WC:2LM	986.83
1WC:2HM	1341.70
1WC:1LM:1HM	1154.27

Table A.17: The cumulative amount of CO_2 [g kg^{-1}] produced during composting period and the other evolved by burning *QR* wood

Mixing ratio	Water type	Infection worm	Duration (days)													
			7	14	21	28	35	42	48	56	63	70	77	84	91	100
1WC:2LM	C	0.0	46.0	122.7	224.0	307.4	387.3	452.3	509.1	555.1	597.4	633.4	660.1	679.1	694.4	710.4
	T	0.0	44.2	120.0	222.2	306.9	377.1	430.3	478.4	515.5	557.2	589.5	609.9	626.2	639.4	652.0
	T	*EF*	47.7	125.5	225.7	307.9	381.4	449.4	506.8	553.7	600.6	646.4	682.3	702.9	719.4	735.7
1WC:2HM	C	0.0	86.1	210.0	340.9	462.4	549.4	642.0	727.9	801.1	871.5	926.6	963.9	989.0	1007.5	1026.0
	T	0.0	84.4	209.2	341.6	463.9	549.2	635.5	718.8	791.0	859.8	902.2	929.7	949.2	964.5	979.2
	T	*EF*	87.8	214.7	344.1	464.9	556.5	651.6	737.1	819.2	894.2	958.1	1001.1	1028.8	1050.4	1071.8
1WC:1LM:1HM	C	0.0	55.0	150.8	272.4	373.9	455.3	526.2	591.5	646.1	707.5	757.5	789.5	811.0	827.9	845.2
	T	0.0	54.3	149.1	271.9	375.4	452.7	521.9	584.1	632.3	684.0	719.3	744.3	762.7	776.9	790.1
	T	*EF*	57.8	154.6	275.9	377.4	457.9	531.5	596.9	650.4	714.4	773.2	810.2	833.8	852.4	870.8
CO_2 produced by burning *QR* wood [g kg^{-1} wood]																1860.8

Data represent averages of three replicates

C= compost water all composting period, T= Tap water after one month compost water

Table A.18: Degree of biodegradation [%] during composting of different studied wood treatments

Mixing ratio	Water type	Infection worm	Duration (days)													
			7	14	21	28	35	42	48	56	63	70	77	84	91	100
1WC:2LM	C	0.0	4.7	12.4	22.7	31.2	39.2	45.8	51.6	56.3	60.5	64.2	66.9	68.8	70.4	72.0
	T	0.0	4.5	12.2	22.5	31.1	38.2	43.6	48.5	52.2	56.5	59.7	61.8	63.5	64.8	66.1
	T	*EF*	4.8	12.7	22.9	31.2	38.6	45.5	51.4	56.1	60.9	65.5	69.1	71.2	72.9	74.6
1WC:2HM	C	0.0	6.4	15.6	25.4	34.5	40.9	47.9	54.3	59.7	65.0	69.1	71.8	73.7	75.1	76.5
	T	0.0	6.3	15.6	25.5	34.6	40.9	47.4	53.6	59.0	64.1	67.2	69.3	70.7	71.9	73.0
	T	*EF*	6.5	16.0	25.6	34.7	41.5	48.6	54.9	61.1	66.6	71.4	74.6	76.7	78.3	79.9
WC:1LM:1HM	C	0.0	4.5	12.2	22.5	31.1	38.2	43.6	48.5	52.2	56.5	59.7	61.8	63.5	64.8	66.1
	T	0.0	4.7	12.9	23.6	32.5	39.2	45.2	50.6	54.8	59.3	62.3	64.5	66.1	67.3	68.5
	T	*EF*	5.0	13.4	23.9	32.7	39.7	46.0	51.7	56.4	61.9	67.0	70.2	72.2	73.8	75.4

Data represent averages of three replicates

C= compost water all composting period, T= Tap water after one month compost water

Table A.19: Organic matter content [%] during composting of different studied wood treatments

Mixing ratio	Water type	Infection worm	Duration (days)							
			7	14	28	42	56	70	84	100
1WC:2LM	C	0.0	47.9	45.7	43.4	41.7	39.5	38.3	37.1	35.8
	T	0.0	47.9	45.2	43.1	42.5	42.3	41.6	38.7	37.6
	T	*EF*	47.1	45.7	43.7	39.3	37.6	36.2	31.5	30.5
1WC:2HM	C	0.0	72.4	69.5	64.9	62.4	55.6	47.3	41.3	39.9
	T	0.0	72.9	69.7	64.2	63.3	61.7	57.0	51.3	47.4
	T	*EF*	72.3	69.0	64.8	55.5	48.7	40.7	36.0	35.4
1WC:1LM:1HM	C	0.0	59.0	58.6	57.0	53.3	49.0	44.3	39.5	38.0
	T	0.0	59.0	58.1	56.2	55.4	52.6	46.3	42.3	39.5
	T	*EF*	58.4	58.7	57.0	48.2	44.3	39.1	33.5	33.4

Data represent averages of three replicates

C= compost water all composting period, T= Tap water after one month compost water

Table A.20: Total Organic carbon content [%] during composting of different studied wood treatments

Mixing ratio	Water type	Infection worm	Duration (days)							
			7	14	28	42	56	70	84	100
1WC:2LM	C	0.0	27.8	26.5	25.2	24.2	23.9	22.2	21.5	20.7
	T	0.0	27.8	26.2	25.0	24.7	24.6	24.1	23.5	22.8
	T	*EF*	27.3	26.5	25.3	22.8	21.8	21.0	18.3	17.7
1WC:2HM	C	0.0	40.0	38.3	37.7	36.2	32.3	27.5	25.0	23.6
	T	0.0	40.3	38.4	37.2	36.7	33.8	31.1	28.8	27.5
	T	*EF*	39.9	38.0	37.6	32.2	28.3	23.6	21.7	20.8
1WC:1LM:1HM	C	0.0	34.2	33.6	32.1	30.9	28.4	25.7	22.9	22.1
	T	0.0	34.2	33.7	32.6	31.1	29.5	26.8	24.5	23.9
	T	*EF*	33.9	34.1	33.1	27.9	25.7	22.7	19.9	19.2

Data represent averages of three replicates

C= compost water all composting period, T= Tap water after one month compost water

Table A.21: Total extractable carbon content [%] during composting of different studied wood treatments

Mixing ratio	Water type	Infection worm	Duration (days)							
			7	14	28	42	56	70	84	100
1WC:2LM	C	0.0	16.4	15.7	15.0	14.4	13.8	13.6	13.4	13.0
	T	0.0	16.4	15.6	14.9	14.7	14.6	13.4	13.2	13.1
	T	*EF*	16.2	15.7	15.1	13.7	13.1	12.7	12.2	11.8
1WC:2HM	C	0.0	22.3	22.4	21.9	21.1	18.9	16.3	15.3	14.5
	T	0.0	22.5	21.5	20.7	20.4	19.9	19.4	17.5	17.3
	T	*EF*	22.3	21.2	20.9	17.9	16.7	15.1	14.0	13.8
1WC:1LM:1HM	C	0.0	19.5	19.6	19.4	18.2	16.8	15.3	14.4	13.9
	T	0.0	19.0	18.9	18.1	17.8	18.0	16.9	15.6	15.2
	T	*EF*	18.8	19.0	18.4	16.5	15.3	13.6	13.5	12.7

Data represent averages of three replicates

C= compost water all composting period, T= Tap water after one month compost water

Table A.22: Total carbon content [%] during composting of different studied wood treatments

Mixing ratio	Water type	Infection worm	Duration (days)							
			7	14	28	42	56	70	84	100
1WC:2LM	C	0.0	29.5	27.3	26.7	26.3	25.2	24.6	24.2	23.1
	T	0.0	29.5	27.7	26.7	26.2	26.1	25.5	25.3	25.4
	T	*EF*	29.1	28.4	26.1	24.6	24.2	23.5	22.2	21.2
1WC:2HM	C	0.0	43.0	41.9	40.6	37.3	33.9	29.4	28.5	28.3
	T	0.0	42.9	42.4	41.1	39.8	38.9	37.1	33.7	32.7
	T	*EF*	42.5	41.8	41.5	35.8	31.8	27.3	24.8	24.2
1WC:1LM:1HM	C	0.0	35.4	35.4	34.5	32.7	30.5	27.9	27.3	26.3
	T	0.0	35.1	35.1	35.1	34.7	33.3	31.1	31.2	30.4
	T	*EF*	35.4	35.4	35.7	31.1	29.1	27.9	23.8	23.4

Data represent averages of three replicates

C= compost water all composting period, T= Tap water after one month compost water

Table A.23: Total nitrogen content [%] during composting of different studied wood treatments

Mixing ratio	Water type	Infection worm	Duration (days)							
			7	14	28	42	56	70	84	100
1WC:2LM	C	0.0	0.98	0.99	1.03	1.04	1.08	1.14	1.20	1.27
	T	0.0	0.98	0.99	1.04	1.02	1.06	1.06	1.11	1.15
	T	*EF*	1.00	1.01	1.02	1.06	1.10	1.17	1.26	1.40
1WC:2HM	C	0.0	1.69	1.70	1.71	1.84	1.88	1.95	2.00	2.11
	T	0.0	1.70	1.72	1.71	1.80	1.85	1.90	1.95	1.98
	T	*EF*	1.68	1.70	1.74	1.85	2.01	2.04	2.08	2.22
1WC:1LM:1HM	C	0.0	1.37	1.38	1.39	1.50	1.53	1.64	1.72	1.77
	T	0.0	1.35	1.36	1.42	1.49	1.51	1.55	1.60	1.66
	T	*EF*	1.37	1.37	1.44	1.53	1.55	1.67	1.79	1.83

Data represent averages of three replicates

C= compost water all composting period, T= Tap water after one month compost water

Table A.24: C:N ratio during composting of different studied wood treatments

Mixing ratio	Water type	Infection worm	Duration (days)							
			7	14	28	42	56	70	84	100
1WC:2LM	C	0.0	30.1	27.6	25.9	25.3	23.4	21.6	20.1	18.2
	T	0.0	30.1	27.9	25.7	25.7	24.7	24.0	22.8	22.1
	T	*EF*	29.1	28.1	25.6	23.2	22.0	20.1	17.6	15.1
1WC:2HM	C	0.0	25.4	24.7	23.7	20.3	18.0	15.1	14.3	13.4
	T	0.0	25.2	24.6	24.0	22.1	21.0	19.5	17.3	16.5
	T	*EF*	25.3	24.6	23.9	19.4	15.8	13.4	11.9	10.9
1WC:1LM:1HM	C	0.0	25.8	25.6	24.8	21.8	19.9	17.0	15.9	14.9
	T	0.0	26.0	25.8	24.7	23.3	22.1	20.1	19.5	18.3
	T	*EF*	25.8	25.9	24.8	20.3	18.8	16.7	13.3	12.8

Data represent averages of three replicates

C= compost water all composting period, T= Tap water after one month compost water

Table A.25: pH values during composting of different studied wood treatments

Mixing ratio	Water type	Infection worm	Duration (days)							
			7	14	28	42	56	70	84	100
1WC:2LM	C	0.0	7.63	7.24	7.13	7.11	7.20	7.20	7.30	7.35
	T	0.0	7.62	7.25	7.11	7.15	7.27	7.26	7.41	7.40
	T	*EF*	7.66	7.30	7.15	7.11	7.11	7.23	7.35	7.37
1WC:2HM	C	0.0	7.33	6.82	6.60	6.63	6.68	6.80	6.90	6.90
	T	0.0	7.33	6.80	6.57	6.66	6.70	6.80	6.90	6.95
	T	*EF*	7.33	6.85	6.63	6.60	6.66	6.70	6.85	6.88
1WC:1LM:1HM	C	0.0	7.51	7.17	6.80	6.85	6.90	6.90	7.00	7.05
	T	0.0	7.50	7.11	6.80	6.88	6.91	6.90	7.11	7.13
	T	*EF*	7.55	7.15	6.86	6.80	6.85	6.85	7.05	7.05

Data represent averages of three replicates

C= compost water all composting period, T= Tap water after one month compost water

Table A.26: Humic acid content [%] during composting of different studied wood treatments

Mixing ratio	Water type	Infection worm	Duration (days)							
			7	14	28	42	56	70	84	100
1WC:2LM	C	0.0	4.6	4.9	5.0	5.3	5.5	5.2	5.1	5.2
	T	0.0	4.8	4.8	5.1	5.2	5.3	5.0	4.8	4.8
	T	*EF*	4.5	5.0	4.9	5.3	5.7	5.4	5.4	5.6
1WC:2HM	C	0.0	7.9	8.2	8.2	8.7	8.2	7.8	7.5	7.6
	T	0.0	7.8	8.2	8.3	8.4	7.7	7.4	7.1	7.2
	T	*EF*	8.0	8.1	8.1	9.0	8.7	8.0	7.7	7.8
1WC:1LM:1HM	C	0.0	6.3	6.5	6.6	7.0	6.9	6.5	6.4	6.5
	T	0.0	6.2	6.2	6.7	6.8	6.5	6.2	6.0	6.0
	T	*EF*	6.3	6.3	6.5	7.1	7.2	6.9	6.8	6.9

Data represent averages of three replicates

C= compost water all composting period, T= Tap water after one month compost water

Table A.27: Fulvic acid content [%] during composting of different studied wood treatments

Mixing ratio	Water type	Infection worm	Duration (days)							
			7	14	28	42	56	70	84	100
1WC:2LM	C	0.0	1.8	1.9	1.9	2.2	2.4	2.5	2.1	2.0
	T	0.0	1.7	1.9	2.0	2.1	2.1	2.1	1.9	1.7
	T	*EF*	1.8	1.9	1.9	2.4	2.7	2.8	2.4	2.2
1WC:2HM	C	0.0	2.8	2.9	3.5	3.8	3.9	4.2	4.0	3.8
	T	0.0	2.8	2.8	3.4	3.6	3.6	3.7	3.5	3.3
	T	*EF*	2.6	2.9	3.3	4.0	4.2	4.7	4.5	4.3
1WC:1LM:1HM	C	0.0	2.3	2.4	2.7	3.0	3.2	3.3	3.1	2.9
	T	0.0	2.2	2.3	2.5	2.8	2.9	2.9	2.7	2.5
	T	*EF*	2.1	2.2	2.7	3.2	3.4	3.5	3.3	3.0

Data represent averages of three replicates

C= compost water all composting period, T= Tap water after one month compost water

Table A.28: Degree of humification [%] during composting of different studied wood treatments

Mixing ratio	Water type	Infection worm	Duration (days)							
			7	14	28	42	56	70	84	100
1WC:2LM	C	0.0	38.8	43.0	46.0	51.7	57.3	55.8	54.0	55.1
	T	0.0	39.2	43.2	47.3	49.3	50.9	52.6	50.0	50.0
	T	*EF*	38.7	43.2	44.9	56.0	64.0	64.4	64.2	65.7
1WC:2HM	C	0.0	47.8	49.3	53.6	58.9	63.9	73.5	75.0	78.7
	T	0.0	47.0	51.5	56.5	58.4	56.9	56.9	60.7	60.6
	T	*EF*	47.6	51.7	55.0	72.3	77.2	83.8	87.5	87.9
1WC:1LM:1HM	C	0.0	43.7	45.5	48.1	54.7	59.7	64.3	65.6	67.1
	T	0.0	44.2	46.7	50.8	53.7	52.2	53.5	55.2	55.9
	T	*EF*	44.5	44.8	50.2	62.4	69.6	76.5	75.0	78.5

Data represent averages of three replicates

C = compost water all composting period, T = Tap water after one month compost water

Table A.29: Humification rate [%] during composting of different studied wood treatments

Mixing ratio	Water type	Infection worm	Duration (days)							
			7	14	28	42	56	70	84	100
1WC:2LM	C	0.0	22.9	25.5	27.4	30.9	33.1	34.3	33.5	34.6
	T	0.0	23.2	25.6	28.1	29.4	30.3	29.3	28.1	28.7
	T	*EF*	22.9	25.6	26.7	33.6	38.5	38.8	42.7	43.9
1WC:2HM	C	0.0	26.7	27.4	31.2	34.3	37.5	43.5	46.0	48.5
	T	0.0	26.2	27.4	31.4	32.5	33.5	35.5	37.0	38.1
	T	*EF*	26.6	27.4	30.5	40.2	45.6	53.7	56.2	58.1
1WC:1LM:1HM	C	0.0	24.9	26.5	29.1	32.1	35.2	38.2	41.2	42.4
	T	0.0	24.6	26.2	28.2	30.8	31.8	33.7	35.2	35.6
	T	*EF*	24.7	25.0	27.9	36.9	41.4	45.9	50.9	51.9

Data represent averages of three replicates

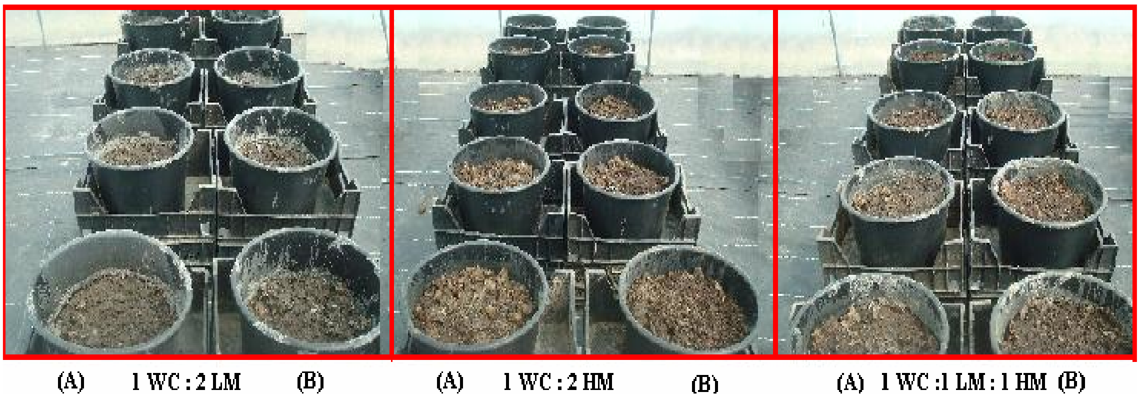
C = compost water all composting period, T = Tap water after one month compost water

Table A.30: Humification index during composting of different studied wood treatments

Mixing ratio	Water type	Infection worm	Duration (days)							
			7	14	28	42	56	70	84	100
1WC:2LM	C	0.0	1.58	1.32	1.18	0.93	0.75	0.79	0.85	0.82
	T	0.0	1.55	1.32	1.12	1.03	0.97	0.90	1.00	1.00
	T	*EF*	1.58	1.31	1.23	0.78	0.56	0.55	0.56	0.52
1WC:2HM	C	0.0	1.09	1.03	0.87	0.70	0.56	0.36	0.33	0.27
	T	0.0	1.13	0.94	0.77	0.71	0.76	0.76	0.65	0.65
	T	*EF*	1.10	0.93	0.82	0.38	0.30	0.19	0.14	0.14
1WC:1LM:1HM	C	0.0	1.29	1.20	1.08	0.83	0.68	0.55	0.53	0.49
	T	0.0	1.26	1.21	0.97	0.86	0.91	0.87	0.81	0.79
	T	*EF*	1.25	1.23	0.99	0.60	0.44	0.31	0.33	0.27

Data represent averages of three replicates

C = compost water all composting period, T = Tap water after one month compost water



(A) 1 WC : 2 LM (B) (A) 1 WC : 2 HM (B) (A) 1 WC :1 LM : 1 HM (B)

Fig. A. 4: Design of second compost trial for the treatments has not infected with worms

(A) Pots irrigated with compost water all composting period and without worms infection

(B) Pots irrigated with compost water for one month, after that tap water until the end of trial, and without worms infection

1 WC : 2 LM + EF 1 WC : 2 HM + EF 1 WC : 1 LM : 1 HM + EF

Fig. A. 5: Design of second compost trial for the treatments has infected with worms

8.3. Greenhouse plant experiment

Table A.31: Physical soil properties as affected by different application rates of vermicompost (data represent averages of three replicates)

Vermicompost application ratios [%]	WHC [%]	BD [g cm^{-3}]	PD [g cm^{-3}]	TP [%]
0.0	30.83 c	1.33 a	2.39 a	44.29 c
3.0	32.70 c	1.31 a	2.36 a	44.34 c
12.5	58.22 b	1.18 b	2.28 b	48.17 b
25.0	72.60 a	1.04 c	2.19 c	52.59 a
LSD $_{0.05}$	2.91	0.04	0.04	2.54

Mean of the same category followed by different letters are significantly different at 0.05 level of probability.

Table A.32: Chemical soil properties as affected by different application rates of vermicompost (data represent averages of three replicates)

Properties	Unit	Vermicompost application ratios [%]				LSD $_{0.05}$
		0.0	3.0	12.5	25.0	
EC	[dS m^{-1}]	0.23 d	0.35 c	0.66 b	0.83 a	0.09
pH	-	3.73 c	5.22 b	7.39 a	7.61 a	0.38
TOC	[%]	1.22 c	1.44 c	2.17 b	3.15 a	0.57
OM	[%]	2.45 c	2.87 c	4.27 b	6.97 a	0.54
TN	[g kg^{-1}]	0.39 d	0.52 c	1.12 b	2.13 a	0.07
TC		12.20 c	12.97 c	24.37 b	39.47 a	2.18
C:N ratio	-	31.28 d	24.94 c	21.76 b	18.53 a	1.29
TS	[%]	0.21 c	0.22 c	0.27 b	0.31 a	0.03

Mean of the same category followed by different letters are significantly different at 0.05 level of probability.

Table A.33: Basic and acid soil buffering capacity as affected by different applications rates of vermicompost (data represent averages of three replicates)

VAR[a] [%]	ACS[b]	Volume [ml] 0.1 M HCl					DW[d] [ml]	Volume [ml] 0.1 M NaOH					BCS[c]
		16.0	8.0	4.0	2.0	1.0	100.0	1.0	2.0	4.0	8.0	16.0	
		pH [1:10] soil : solution											
0.0	-0.10	2.24	2.60	2.83	3.16	3.48	4.23	5.75	6.34	6.74	7.26	10.13	0.31
3.0	-0.10	3.15	3.44	3.75	4.33	4.50	4.75	6.30	6.58	7.63	8.25	10.10	0.29
12.5	-0.07	6.17	6.53	6.85	6.95	7.08	7.31	7.51	7.71	8.43	9.09	10.04	0.17
25.0	-0.05	6.63	6.97	7.19	7.32	7.39	7.46	7.49	7.61	8.19	8.89	9.87	0.16

[a] = Vermicompost application ratios, [b] = Acid curve slope, [c] = Base curve slope, and [d] = Distilled water.

Table A.34: Fresh weight [g pot^{-1}], relative increase [%] and its agronomic efficiency of both straw and roots of the plants as affected by different application rates of vermicompost (data represent averages of three replicates)

VAR[a] [%]	Straw			Root		
	FMY[b] [g pot^{-1}]	RI[c] [%]	AE[d]	FMY[b] [g pot^{1}]	RI[c] [%]	AE[d]
0.0	0.85 d			0.30 d		
3.0	1.94 c	128.24	0.36	0.72 c	140.00	0.14
12.5	7.26 b	754.12	0.51	2.51 b	736.67	0.18
25.0	9.12 a	972.94	0.33	3.05 a	916.67	0.11
LSD $_{0.05}$	0.75			0.30		

Mean of the same category followed by different letters are significantly different at 0.05 level of probability.

[a] = Vermicompost application ratios, [b] = Fresh matter yield, [c] = relative increase, [d] = agronomic efficiency (see Eq. 3.14 and 15).

Table A.35: Dry weight [g pot^{-1}], relative increase [%] and its agronomic efficiency of both straw and roots of the plants as affected by different application rates of vermicompost (data represent averages of three replicates)

VAR[a] [%]	Straw			Root		
	DMY[b] [g pot^{-1}]	RI[c] [%]	AE[d]	DMY[b] [g pot^{-1}]	RI[c] [%]	AE[d]
0.0	0.15 d			0.06 d		
3.0	0.33 c	120.00	0.06	0.12 c	100.00	0.02
12.5	1.33 b	786.67	0.08	0.44 b	633.33	0.03
25.0	1.56 a	940.00	0.06	0.53 a	783.33	0.02
LSD $_{0.05}$	0.09			0.03		

Mean of the same category followed by different letters are significantly different at 0.05 level of probability

[a] = Vermicompost application ratios, [b] = Dry matter yield, [c] = relative increase, [d] = agronomic efficiency (see Eq. 3.14 and 15)

8.4. Field plant experiment

Table A.36: Effect of wood compost and ARK component on plant properties of grass grown in tertiary sand (data represent averages of triplicates in each treatment)

Treatments	Height [cm]		Covering [%]		FMY (straw) [g m^{-2}]		DMY			
							Straw [g m^{-2}]		Root [g m^{-2}]	
	R	A	R	A	R	A	R	A	R	A
T1 (100-0-0)	5.0 c	5.0 c	1.0 d	1.0 d	0.4 e	6.4 e	0.2 e	2.4 e	3.8 d	6.0 d
T2 (97-0-3)	12.0 b	15.0 b	60.0 c	70.0 c	248.8 d	302.2 d	112.9 d	105.6 d	144.6 c	104.2 c
T3 (95-0-5)	12.0 b	17.0 b	70.0 b	80.0 b	516.8 c	501.0 c	203.2 c	156.4 c	333.0 b	173.0 b
T4 (90-0-10)	20.0 a	20.0 a	90.0 a	95.0 a	1165.4 a	1140.6 a	412.8 a	282.4 a	497.0 a	234.6 a
T5 (94-3-3)	12.0 b	15.0 b	70.0 b	70.0 c	273.4 d	344.6 d	125.4 d	117.8 d	156.0 c	112.6 c
T6 (90-5-5)	20.0 a	20.0 a	90.0 a	95.0 a	596.0 b	742.6 b	234.4 b	221.6 b	337.0 b	182.0 b
T7 (85-7.5-7.5)	20.0 a	20.0 a	90.0 a	95.0 a	599.6 b	761.6 b	235.2 b	226.6 b	342.0 b	185.6 b
LSD $_{0.05}$	5.74	3.64	8.46	9.34	133.97	138.02	17.79	13.98	13.99	10.72

Mean of the same category followed by different letters are significantly different at 0.05 level of probability

R = *RSM* 7.2.1 grass, A = Autochthonous grass

Table A.37: Effect of wood compost and ARK component on plant properties of grass grown in quaternary sand (data represent averages of triplicates in each treatment)

Treatments	Height [cm]		Covering [%]		FMY (straw) [g m^{-2}]		DMY			
							Straw [g m^{-2}]		Root [g m^{-2}]	
	R	A	R	A	R	A	R	A	R	A
Q1(100-0-0)	5.0 d	5.0 d	10.0 e	10.0 e	7.8 e	24.4 e	1.0 e	4.4 e	6.7 e	6.4 e
Q2 (90-5-5)	12.0 a	15.0 a	75.0 a	80.0 a	366.8 a	656.4 a	86.6 a	203.2 a	215.4 a	88.0 a
Q3 (94-3-3)	10.0 b	10.0 b	60.0 b	75.0 a	318.0 b	506.8 b	75.4 b	165.6 b	185.2 b	79.4 a
Q4 (97-1.5-1.5)	10.0 b	10.0 b	40.0 c	40.0 c	192.2 d	208.8 d	51.0 d	61.2 d	133.4 c	53.0 c
Q5 (97-0-3)	10.0 b	10.0 b	55.0 b	60.0 b	231.2 c	293.8 c	62.8 c	88.6 c	146.6 c	66.8 b
Q6 (98.75-0-1.25)	8.0 c	8.0 c	30.0 d	30.0 d	180.6 d	193.2 d	47.0 d	57.4 d	60.2 d	31.4 d
LSD $_{0.05}$	1.77	1.49	7.43	9.04	17.96	11.56	9.89	17.83	15.02	10.84

Mean of the same category followed by different letters are significantly different at 0.05 level of probability

R = *RSM* 7.2.1 grass, A = Autochthonous grass

DECLARATION

I hereby solemnly declare that, I submitted the thesis entitled "Wood compost- process engineering, properties and its impact on extreme soil characteristics" in order to obtain the academic degree "doctor rerum naturalium" (Dr. rer. nat.) from Institut für Erd- und Umweltwissenschaften, Mathematisch-Naturwissenschaftlichen Fakultät, Universität Potsdam.

I certify that, I have prepared this dissertation independently and without unauthorized assistance. This dissertation did not submit at any other institute, faculty and university. I also declare that the work specified only with the funds was made. The present work was made independently and exclusively with the given resources and tools.

Potsdam, den 21 . 02 . 2011

Wael Mohamed Nada